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See Sectional List No. 45 for titles of individual papers.

BULLETIN No. 29. Published April, 1969. Price £1 (by post £1 1*s*. 2*d*.).

I.—The stratigraphy of the Geological Survey Apley Barn Borehole, Witney, Oxfordshire, by E. G. Poole, B.Sc., with appendices by G. A. Kellaway, B.Sc., E. G. Poole, B.Sc., H. F. Adams, M.Sc., J. R. Bennett, B.Sc. and J. Taylor, B.Sc.

II.—The Putcheons Farm (1965) Borehole, Redditch, Worcestershire, by E. G. Poole, B.Sc.

III.—The Permian Igneous Rocks of Devon, by Diane C. Knill, Ph.D., D.I.C.

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NATURAL ENVIRONMENT RESEARCH COUNCIL

INSTITUTE OF GEOLOGICAL SCIENCES

Bulletin

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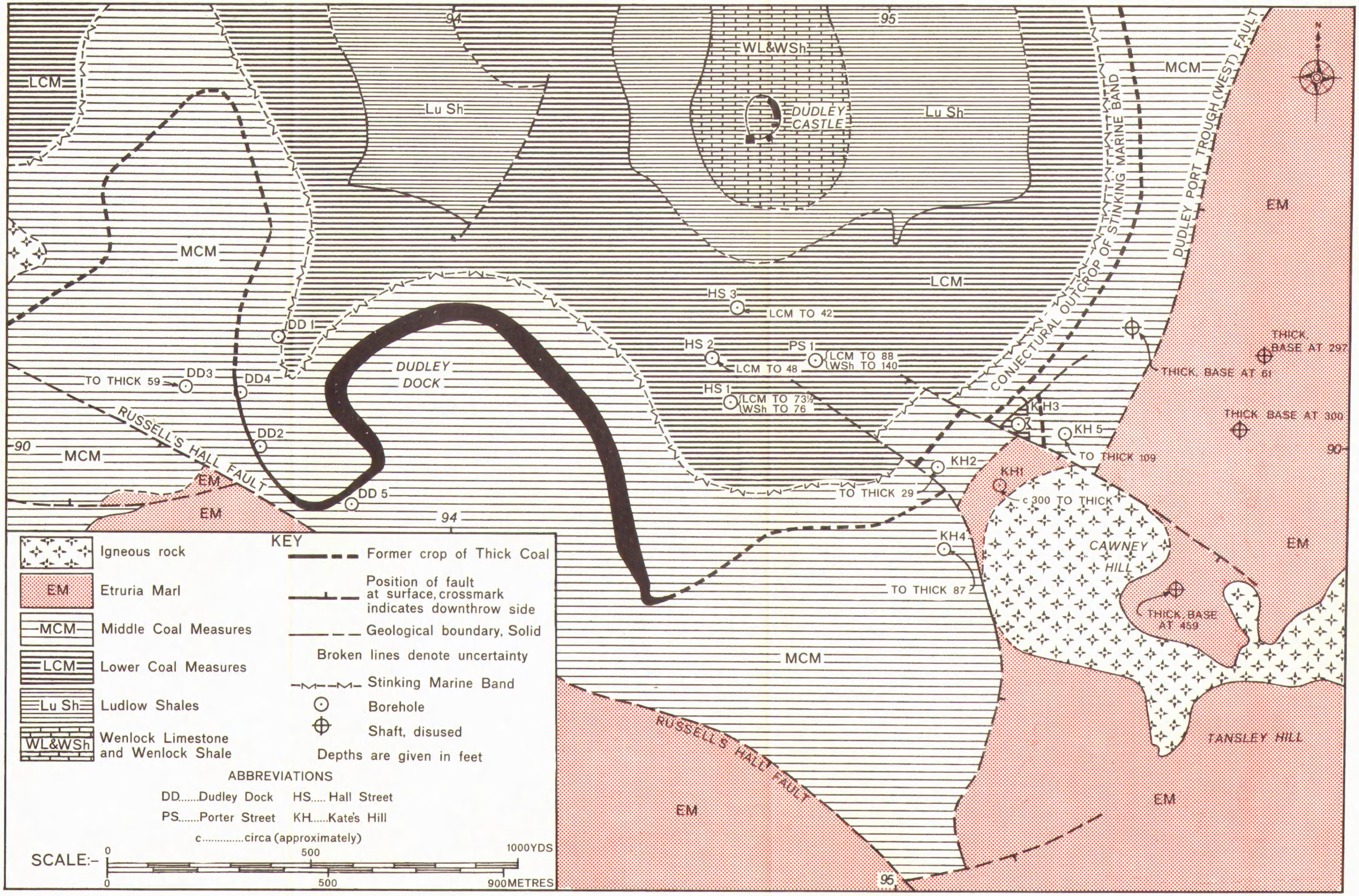

SKETCH MAP SHOWING SOLID GEOLOGY OF THE DUDLEY AREA

I.—TRIAL BOREHOLES IN COAL MEASURES AT DUDLEY, WORCESTERSHIRE

BY

E. G. POOLE, B.SC.

Plates I–II; Text-figures 1–3

Summary. The redevelopment of Dudley, Worcestershire, with the construction of multi-storey buildings in an area where widespread mining for coal, ironstone and limestone has been carried out in the past necessitated the sinking of several trial boreholes into the Coal Measures as part of extensive site investigations. These boreholes have provided the basis for a detailed modern account of the Middle and Lower Coal Measures sequence in the worked-out central part of the South Staffordshire Coalfield. Old workings were encountered in the Thick, Heathen and Stinking coals and probably also in the Whitestone Ironstone. Only two marine bands were encountered in the Middle Coal Measures sequence, the upper one occurring beneath the Brooch Coal and the lower one representing the Stinking Marine Band which occurs near the middle of the *Anthraconaia modiolaris* Zone. In certain of the boreholes thick dolerite sills were encountered; these have had but little metamorphic effect upon the Coal Measures into which they are intruded. This contrasts strongly with the metamorphic effect produced by underground fires in the old workings in the Thick Coal of the Dudley Dock and Eve Hill areas which have baked the clays and shales underlying and overlying the coal and recrystallized much of the Dudley Thick Coal Rock to a quartzite. Primary red beds of Etruria Marl facies occur above the Brooch Coal and also below the horizon of the Mealy Grey Coal in the lowermost part of the Lower Coal Measures sequence. By comparison with the National Coal Board Hamstead No. 1 Borehole farther east it appears that the Etruria Marl facies is developed at lower horizons in the Wassel Grove–Dudley–Penn area and that the Charles Marine Band has been replaced laterally in this area by primary red beds.

INTRODUCTION

SITE INVESTIGATIONS in the Old Dock, New Dock, Hall Street and Kate's Hill areas of Dudley were carried out in 1961–5 by Geo. Wimpey and Company Limited under the supervision of B. E. Poole, Esq., F.R.I.C.S., A.M.I.Min.E., C.Eng., consultant mining engineer for the County Borough of Dudley. We are indebted to the Borough Engineer and Surveyor, D. S. Warren, Esq., C.Eng., M.I.C.E., M.I.Mun.E., for allowing us to examine the cores and to publish the results from these trial boreholes and to Mr. B. E. Poole for his invaluable help and advice on the local geology of Dudley. His description of the Hall Street boreholes is included in Appendix I (pp. 18–20). The results of the Dudley Dock boreholes (28 uncored probes to prove the Stinking Coal and 34 trial pits in the Dock area) were incorporated in the site investigation report to Dudley County Council prepared by I. E. Higginbottom, Esq., B.Sc., A.R.C.S., A.M.I.M.E., of the Central Laboratory, Geo. Wimpey and Company Limited, Hayes. This report clearly proves the extent of the old workings in the Thick Coal and the position of the Stinking Marine Band in the Dudley Dock area.

Also included in the present account are the results of the Porter Street Borehole which was sunk in 1965 by G. K. N. Foundations Limited as part of another site investigation in Dudley carried out under the supervision of their consultants, K. Wardell and Partners, who kindly allowed Mr. L. S. O. Morris to inspect the cores.

A sketch-map showing the revised geology of the area and the position of the more important shafts and boreholes is given in Plate I. In order to facilitate the correlation of the Kate's Hill No. 1 Borehole accounts of the Hamstead

No. 1 and the Penn (Baggeridge) No. 1 boreholes are incorporated. The Hamstead No. 1 Borehole is situated about 9 miles to the east-north-east of the town and was sunk by the Bremner Company for the West Midlands Division of the National Coal Board in 1948–9; it was examined by Mr. L. S. O. Morris and Dr. G. H. Mitchell of the Geological Survey. The Penn No. 1 Borehole is situated about 5 miles to the north-west of Dudley (Fig. 2) and was sunk by the Craelius Company for the West Midlands Division of the National Coal Board in 1954–55 as part of an exploration programme for Baggeridge Colliery. It was examined by Mr. R. H. Hoare, then of the Geological Survey, now Regional Geologist of the National Coal Board's North West Region. From the evidence of the Hamstead No. 1 Borehole (pp. 20–3), it would appear that the marine band encountered in the Kate's Hill No. 1 Borehole is the Sub-Brooch rather than the Charles Marine Band, the latter being replaced laterally by beds of Etruria Marl facies (Fig. 2).

General Stratigraphy

The Coal Measures of the South Staffordshire Coalfield have long been subdivided on lithostratigraphic criteria into Upper Coal Measures (including the Enville Beds, Keele Beds, Halesowen Beds and Etruria Marl) and Middle (Productive) Coal Measures (Whitehead and Eastwood 1927, p. 6). Nowadays the junction of the Upper and Middle Coal Measures in England and Wales is taken at the top of the marine band with *Anthracoceras cambriense* Bisat as its characteristic goniatite and the junction between Middle and Lower Coal Measures is taken at the base of the marine band which occurs at about the middle of the Zone of *Anthraconaia modiolaris* and which contains *Anthracoceras vanderbeckei* (Ludwig) as its characteristic goniatite (Stubblefield and Trotter 1957, pp. 2–3).

The *Anthracoceras cambriense* Marine Band is not developed in the southern part of the South Staffordshire Coalfield where the uppermost marine horizon in the sequence is normally the Charles Marine Band. This occurs at the junction of the Lower and Upper *Anthracosia similis-Anthraconaia pulchra* zones. In the Claverley (Gibson 1913, p. 39) and Hamstead No. 1 (Fig. 1) boreholes, the Charles Marine Band is overlain by nearly 200 ft of red measures of Etruria Marl facies, which are in turn overlain by the Halesowen Group of late Upper Coal Measures age. Whitehead (*in* Whitehead and Pocock 1947, p. 59) has suggested that the base of the Upper Coal Measures in the Dudley district (Sheet 167) should be taken at the top of the Charles Marine Band. However it is almost certain that at least some of the lowermost Etruria Marl facies hereabouts is actually of Upper *similis-pulchra* Zone age.

In the Wyre Forest Coalfield this marine band is termed the Eymore Farm Marine Band (Whitehead and Pocock 1947, p. 42; Poole 1966, pp. 139–40) and is overlain and underlain by red beds of Etruria Marl facies (Fig. 1) but in the immediate vicinity of Dudley the Charles Marine Band is absent and is replaced by red measures of Etruria Marl facies (Fig. 1). The highest marine band in the sequence is the Sub-Brooch Marine Band (Figs. 1, 2) situated about 50 ft below the base of the red measures. This marine band is well known in the northern part of the South Staffordshire Coalfield and Cannock Chase area where it generally reaches a thickness of 2 to 3 ft. It proved to be 5 ft thick in the Hamstead No. 1 Borehole and thins westwards to 3 ft 1 inch in the Kate's Hill No. 1

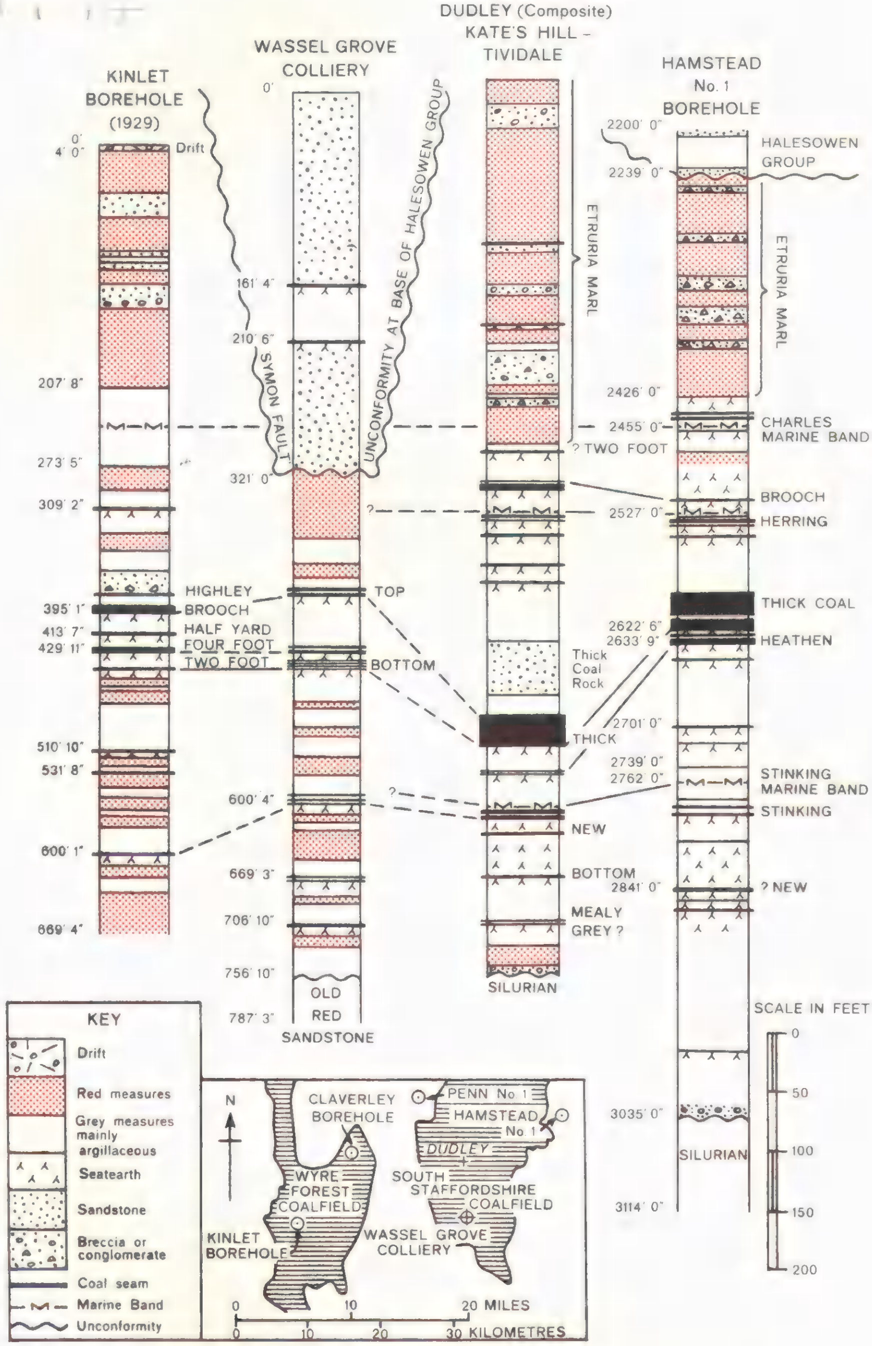

FIG. 1. *Sections showing the occurrence of the red measures in the Kinlet and South Staffordshire Coalfields*

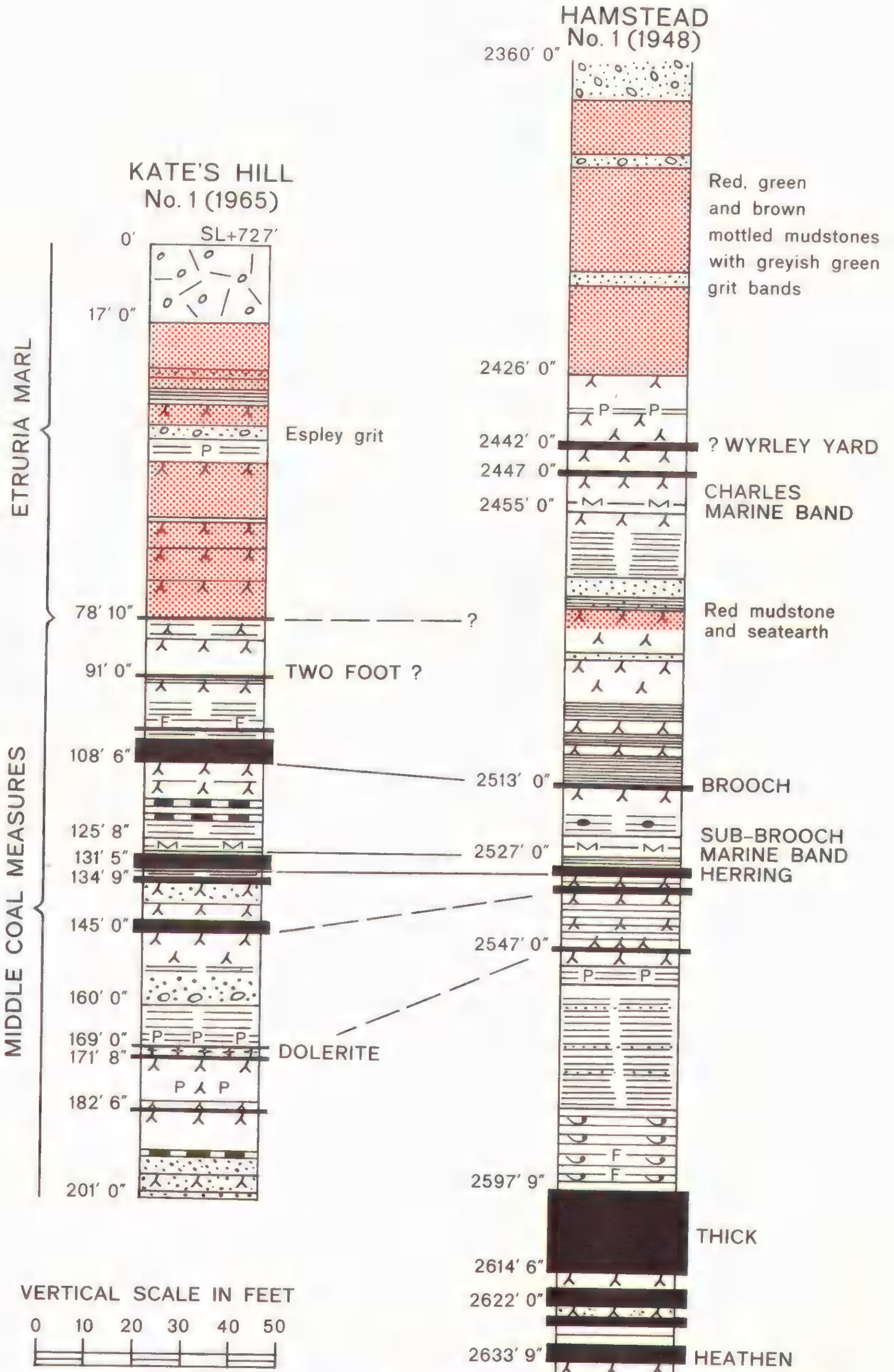

FIG. 2. *The correlation of measures proved above Thick Coal in the Kate's Hill No. 1 Borehole with those of the Hamstead No. 1 Borehole*

Borehole and to only 10 inches in the Penn No. 1 Borehole; more recently it has been proved to be only 9 in thick, base at 123 ft 11 inches, in Borehole H (1968) sunk by Soil Mechanics Limited on a new hospital site at Old Park, Dudley [SO 9215 8933]. It is interesting to note that red measures were recorded at an horizon between the Charles and Sub-Brooch marine bands in the Hamstead No. 1 Borehole (Figs. 1, 2), possibly at the same horizon as the general facies change to Etruria Marl in the Dudley area; they have also been recorded from a similar position beneath the Charles Marine Band in the Claverley Borehole (Gibson 1913, p. 39) and in Sandwell Park No. 1 Colliery (Whitehead and Eastwood 1927, p. 76). Farther afield red measures occur at this position in the Coalbrookdale Coalfield and extend into the Cannock Chase–Rugeley area. Similar red measures have also been noted immediately beneath the Croft's End Marine Band (Charles Marine Band) of the Winterbourne and Yate boreholes sunk in the Coal Pit Heath Basin of the Bristol Coalfield. At Wassel Grove shaft south of Dudley, the base of the Halesowen Group descends unconformably ('Symon Fault') to a position approximating to that of the Sub-Brooch Marine Band (Fig. 1), and red beds of Etruria Marl facies are common throughout the underlying Middle and Lower Coal Measures. The Wassel Grove section correlates fairly well with that of the Kinlet Borehole (Fig. 1) and the Eymore Farm boreholes near Bewdley (Poole 1966, pp. 131–55) and demonstrates the widespread deposition of red beds of Etruria Marl facies in the Middle and Lower Coal Measures in this part of the South Staffordshire and Wyre Forest coalfields.

For practical purposes, however, the present account retains the earlier definition of the top of the Middle (Productive) Coal Measures (Whitehead and Eastwood 1927, p. 6; Whitehead and Pocock 1947, p. 59). This is taken at the facies change from predominantly grey to predominantly red measures (Etruria Marl) which occurs above the Brooch and Two Foot coals or the Charles Marine Band if present. It is recognized that the lower part at least of the diachronous Etruria Marl facies (which is 550 ft thick in the Grace Mary Colliery about 1 mile east of Kate's Hill and nearly 800 ft in Manor Colliery near Halesowen) probably contains primary red beds laterally equivalent to normal grey measures forming the Upper *similis-pulchra* Zone elsewhere. Owing to the absence of the Top Marine Band in these red beds it is impossible to define the actual junction of Upper and Middle Coal Measures.

It is perhaps noteworthy that the Etruria Marl facies of the Kate's Hill No. 1 Borehole passes conformably downwards into grey measures and is made up of many small scale rhythmic units (pp 24–5. In North Staffordshire and South Lancashire, however, the Etruria Marl Group (and the equivalent Barren Group of the South Lancashire Coalfield), which occupies a fairly constant position in the uppermost part of the *Anthraconauta phillipsii* Zone of the Upper Coal Measures, is made up of but a few poorly-developed large scale rhythmic units which show a sequence from variegated, generally unbedded mudstone, sandy mudstone and sandstone down to espley grit (Poole 1966, p. 136).

The new evidence from the Dudley area now makes it possible to subdivide the Middle (Productive) Coal Measures, as formerly classified on the Dudley (167) Sheet, into Lower and Middle Coal Measures using the *Anthracoceras vanderbeckei* (Stinking) Marine Band (Plate I). This marine band has proved to be well developed around Dudley where it overlies the Stinking Coal

(Whitehead and Mitchell *in* Whitehead and Pocock 1947, p. 38) and was found in several of the trial boreholes in the Kate's Hill and Dudley Dock areas of the town. Mr. B. E. Poole has also recorded its presence above the Stinking Coal in many temporary exposures in the vicinity of the town. Here the marine band had a maximum recorded thickness of 10 ft 3 inches in the Dudley Dock No. 5 Borehole (p. 18), but it is thinner to the west and north-west of the town where it has been recorded in the Claverley and Smestow boreholes, Baggeridge Colliery, Straits Colliery and at an opencast coal mine at Woodsetton (Whitehead and Mitchell *in* Whitehead and Pocock 1947, pp. 38–9). It consists of 9 in of pyritous *Lingula*-bearing mudstone in the Penn No. 1 Borehole (Fig. 3). It is well developed generally within the northern part of the South Staffordshire Coalfield where it reaches a maximum thickness of 3 ft (Mitchell 1945, p. 23). To the north-east of Dudley it is known from many boreholes and collieries, notably reaching a thickness of 23 ft in the Hamstead No. 1 Borehole (Fig. 1).

There is, as yet, no record of the presence of the marine band in the extreme southern part of this coalfield (Fig. 1) and it was not recorded in the Kinlet (1929) Borehole though Sir James Stubblefield reports (*in* Whitehead and Pocock 1947, p. 42) "that in the J. T. Stobbs Collection now in the Geological Survey Museum there are specimens of ironstone dated 1920 from 'a crut' at Kinlet Colliery in which he[1] identifies crinoid columnals, a polyzoan, *Orbiculoidea* cf. *nitida*, *Productus* (*Pustula*) *piscariae* Waterlot and *Aviculopecten* cf. *gentilis* (J. de C. Sowerby). The productid is a species characteristic of the Pennystone Ironstone of Coalbrookdale and South Staffordshire (Portway Hall, Dudley)." This would appear to have come from the same horizon as the bed with ironstone nodules in the Kinlet Borehole about 205 ft below the Highley Brooch Coal which overlies the thin coal, base at 600 ft 1 in (Fig. 1) and thus there is at least some evidence for the presence of the Stinking Marine Band in the Kinlet area. In the absence of further evidence, however, it has not proved possible to distinguish between the Lower and Middle Coal Measures of the Wyre Forest Coalfield on the One-inch Geological map (Sheet 167).

Upper Coal Measures

The highest beds of Carboniferous age to be encountered in the present series of boreholes were those of Etruria Marl facies which were proved under 17 ft of superficial deposits in the Kate's Hill No. 1 Borehole down to a depth of 78 ft 10 in (Fig. 2). Owing to their nature they almost certainly include beds of Middle Coal Measures age impossible to distinguish owing to the absence of marine bands or other faunal markers (pp. 24–5). The measures demonstrate small scale rhythmic sedimentation, each rhythm consisting ideally of a thin black carbonaceous plant-rich mudstone band underlain by dark seatearth which rapidly passes downwards into highly variegated green, purple, red, yellow and brown, seatearth-textured unbedded mudstone and sandy mudstone; these unbedded variegated mudstones form the bulk of the rhythmic unit. Thin beds of typical coarse espley-type grit with small quartz pebbles and green mudstone fragments were found between 37 ft and 41 ft 4 in. These red measures passed conformably downwards into normal grey, rhythmically bedded Middle Coal

[1]Sir James Stubblefield

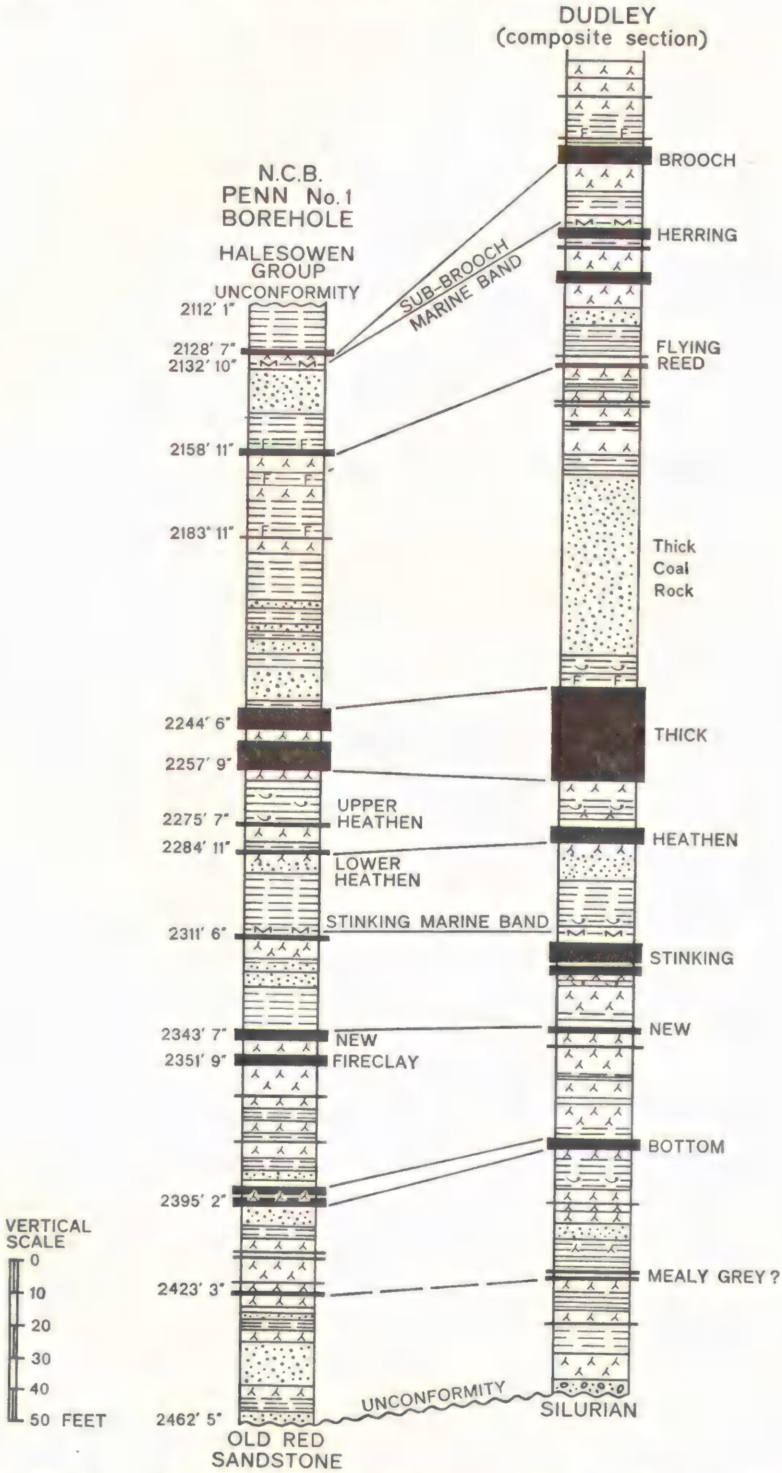

FIG. 3. *Correlation of the Productive Coal Measures proved in the Penn No. 1 Borehole with those of the Dudley area*

Measures at 78 ft 10 in, containing a 7-ft coal seam at 108 ft 6 in and a 2 ft 10-in marine band with its base at 128 ft 6 in (Fig. 2). This coal and marine band correlate with the Brooch Coal and Sub-Brooch Marine Band of the Hamstead No. 1 Borehole and the Penn No. 1 Borehole but it appears that the Charles Marine Band of the Hamstead and Kinlet areas has been replaced laterally by Etruria Marl facies in the Dudley area, there being no marine strata at the corresponding horizon in the Kate's Hill No. 1 Borehole (Fig. 2) and the Penn No. 1 Borehole (Fig. 3).

Middle Coal Measures

Grey beds of Middle Coal Measures age were proved in the Kate's Hill No. 1 Borehole below 78 ft 10 in to a final depth of 201 ft (Fig. 2). The Two Foot Coal in this borehole is probably represented by the inferior coal, coaly mudstone and carbonaceous clay which were recorded between 87 ft 11 in and 91 ft. The Brooch Coal, however, is well developed between 101 ft 6 in and 108 ft 6 in and proved to be of workable thickness and quality, the lowermost 5 ft 8 in being mainly bright good quality coal. The Brooch is overlain by black pyritic mudstone with fish debris and underlain by dark grey silty mudstones with roots in the upper part and ironstone bands and plant debris in the lower part. These beds rest on the Sub-Brooch Marine Band at 125 ft 8 in, here 2 ft 10 in thick, and composed of dark grey, iron-rich mudstone with pyritized foraminifera, ?worm trails and large *Lingula sp*. It rests on 3 in of carbonaceous coaly mudstone overlying the Herring Coal, 2 ft 8 in thick, base at 131 ft 5 in. Below the Herring Coal, there is a 1 ft 9-in coal seam, base at 134 ft 9 in, and a 2 ft 7-in seam, base at 145 ft, in a series of dark rooty mudstones and seatearths. An espley-type sandstone occurs between 157 ft 2 in and 160 ft; this bed is very coarse and gritty in its lower part and contains small green mudstone fragments. It rests with a sharply erosive base upon dark grey silty iron-rich mudstones with many plants. An inferior coal seam between 168 ft 4 in and 171 ft 8 in is split by a 1 ft 9-in sill of fine-grained dolerite—presumably an offshoot from the Rowley Regis dolerite mass which forms the summit of Kate's Hill and Tansley Hill. The upper leaf of coal was apparently only slightly affected by thermal metamorphism associated with this dolerite, but the lower leaf is heavy in hand specimen owing to the loss of volatiles and formation of replacement minerals, and contains much ankerite. The borehole continued in dark grey mudstones and seatearths with occasional coaly and iron-rich bands which are probably the Pennyearth measures normally found about 150 ft above the Dudley Thick Coal. Thin sandstone bands occur below 192 ft 8 in and the borehole finished in coarse-grained whitish grey sandstone with gritty grains and green mudstone fragments at a depth of 201 ft (Fig. 2).

It is possible that the Kate's Hill No. 1 Borehole finished at about the horizon of the uppermost leaf of the Dudley Thick Coal Rock and at approximately the same horizon as that proved in the uppermost Carboniferous cores taken in the Kate's Hill No. 4 Borehole (Plate II). This latter borehole encountered superficial deposits to 15 ft and then proved dark grey mudstone with plants and ironstones down to the top of the Dudley Thick Coal Rock at 21 ft 6 in. This is a medium-grained, current-bedded sandstone with carbonaceous wisps down to 57 ft 3 in overlying mudstone with shaly sandstone wisps, plants and ironstone nodules down to 81 ft and smooth grey mudstone with plants and ironstones to 85 ft 3 in; the lower beds correspond to the Ten-Foot Ironstone measures of other parts of the South Staffordshire Coalfield. The immediate roof of the Thick Coal was composed of black, finely micaceous, fairly smooth mudstone and the Thick Coal itself showed 10 ft of good quality bright coal (base at 97 ft) which rested upon 17 ft of dust and fragments which represented worked-out ground. In the Dudley Dock No. 3 Borehole (1961) 15 ft of superficial deposits (probably made ground) rested upon 44 ft of Thick Coal Rock which was composed of reddish brown and fawn fine-grained sandstones and which was metamorphically hardened and reddened along joints from the former fire in the old workings in the Thick and Heathen coals beneath. A 10-ft void was encountered beneath the sandstone to 69 ft then grey clay with red burnt shale fragments occurred to 82 ft (Plate II). In the Dudley Dock No. 2 Borehole (1961) the Heathen Coal, which was 4 ft 6 in thick with its base at 16 ft 6 in, was encountered beneath 12 ft of made ground (probably old workings in the Thick Coal) and a similar succession was encountered in the Dudley Dock No. 4 Borehole (1961) with made ground to 13 ft and the Heathen Coal to 17 ft 9 in (p. 15). An interesting section was seen in the Dudley Dock No. 5 Borehole (1961) where made ground extended to a depth of 4 ft 5 in, grey clay and mudstone to 10 ft 6 in, burnt out cindery gob with dark clay to 21 ft 10 in (workings in the Thick Coal), black coaly shale with burnt patches to 31 ft, brown burnt seatearth to 32 ft, then mudstone and shale with shells, fish remains and red burnt patches overlying 1 ft 10 in of fragmentary coal to 47 ft 10 in which represents the Heathen Coal; this borehole section demonstrates that a fire formerly burned in the old Heathen Coal workings. To the north-west the Thick Coal is split into two seams, the upper one 7 ft 3 in thick, base at 2244 ft 6 in and the lower one 9 ft 7 in thick, base at 2257 ft 9 inches in the Penn No. 1 Borehole (p. 38). The Heathen Coal also splits into an upper and lower leaf in this borehole (Fig. 3).

Shale with well-preserved mussels was found below the Heathen Coal in both the Dudley Dock No. 5 Borehole (1961) and the Kate's Hill No. 4 Borehole (Plate II); in other boreholes the Heathen Coal rests on a thin bed of plant-rich shale which directly overlies the seatearth. The Heathen seatearth becomes sandy in its lower part and about 5 ft below the coal passes into sandy mudstone with sandstone wisps, plant debris and ironstones. These mudstones, which include the White Ironstone and Pennystone measures of the coalfield, become less sandy with depth and are in all about 16 to 20 ft thick in the Dudley boreholes. Limonite-filled cracks due to circulating mine water extend down from the overlying coal workings to a clay horizon in Dudley Dock No. 2 Borehole (1961) at 40 ft 9 in, and core loss at a similar horizon in the nearby No. 3 Borehole (1961) at 97 ft probably indicates former working of the Whitestone Ironstone in this area. A few mussels were recorded in certain of the boreholes from the lowermost beds which rest directly upon the Stinking Marine Band. This marine horizon is well developed in all the Dudley boreholes which penetrated this part of the succession and proved to have a maximum (undisturbed) thickness of 10 ft 1 inch in the Dudley Dock No. 5 (1961) Borehole (p. 18). It consists of grey silty mudstone with abundant pyritized strap-like markings ('fucoids') in the upper part with small pyrite nodules, foraminifera, 'fucoids', scattered *Lingula sp.* and black plant fragments in the remainder of the band and rests directly upon the Stinking (Sulphur) Coal. This coal seam is so named from the abundance of pyrite in its matrix which when burnt gave off sulphurous fumes. The pyrite was probably deposited in the coal seam during the period when it was submerged by the anaerobic waters of the restricted marine environment; it is notable that the marine shales themselves carry an abundance of pyrite throughout in the form of scattered crystals and pyritized fossil fragments.

Lower Coal Measures

The Stinking Coal is well developed in the Dudley area where it is usually about 3 ft thick but on account of its high sulphur content it was rarely worked; locally it has possibly been worked at Forge Pool Colliery, Fallings Heath (Whitehead and Eastwood 1927, p. 42) and at Dibdale Colliery (op. cit., p. 58). To the north-west it thins and was 1 ft thick, base at 2311 ft 6 inches in the Penn No. 1 Borehole. The Dudley Dock No. 4 Borehole (1961) proved that the Stinking Coal has also been worked in the Dock area. In the Dudley Dock No. 1 Borehole (1961) it was proved to consist of coal, 5 ft 1 in; seatearth 11 in on inferior coal and coaly shale 2 ft thick, base at 39 ft 6 in, (Plate II): the Dudley Dock No. 2 Borehole (1961) proved somewhat inferior coal 6 ft 9 in (not bottomed) at 57 ft: the Dudley Dock No. 3 Borehole (1961) proved 5 ft 3 in (not bottomed) of inferior coal at 126 ft: in the Dudley Dock No. 5 Borehole (1961) the uppermost 2 ft 2 in was proved, base at 82 ft. To the east the Stinking Coal was proved to be 2 ft 10 in thick and of good quality, base at 78 ft 1 inch, in the Kate's Hill No. 2 Borehole where it rests upon 2 ft 5 in of seatearth and a 3-ft rather inferior coal seam, base at 83 ft 6 in, which may be the New Mine (Plate II).

The measures below the Stinking Coal in the Dudley Dock No. 1 Borehole (1961) were proved to consist of mainly good quality dark grey seatearths with many ironstone nodules and sphaerosiderites down to 88 ft 6 in where a 1-ft thick coal seam was encountered. This seam, which may be the Bottom Coal (Plate II), was underlain by 6 in of carbonaceous mudstone, 9 in of bright coal and 3 in of shaly mudstone in which the borehole was completed at a total depth of 91 ft (p. 14). The coal seam is thought to correlate with the 3-ft seam (base at 109 ft) in the Dudley Dock No. 4 Borehole (1961) and the 2 ft 6-in coal seam (base at 13 ft 6 in) in the Hall Street No. 2 Borehole. In the Dudley Dock No. 4 Borehole (1961) an inferior seam 1 ft 6 in thick was proved at 76 ft 3 in which possibly represents the Fireclay Coal and the seam at 109 ft was underlain by 10 ft 2 in of green and yellow dolerite (p. 17). The coal seam had been altered by thermal metamorphism associated with this intrusion, the effect of which had been to drive off volatiles and form replacement minerals such as ankerite. The temperature of the intrusion would appear to have been fairly low since the seam was not coked by the heat but was heavy in hand specimen owing to the weight of the replacement minerals. The roof measures of the seam were apparently unaffected, but the thin shales and inferior coals below it were hardened with deposition of hematite (p. 17); a 6-in thick band of dolerite was also found at 121 ft 3 in, the borehole being completed at 122 ft in thermally metamorphosed mudstone.

The Bottom Coal was also encountered in the Kate's Hill No. 3 Borehole where 4 ft of good quality coal with base at 42 ft were obtained. About 40 ft of mudstones and seatearths with ironstones intervened before the Mealy Grey horizon was reached where the following section was recorded (p. 33); coal 1 ft, mudstone 3 in, inferior coal 1 ft. A mussel band with fish scales was found below the Bottom Coal between 46 and 54 ft. To the west, the measures above the Mealy Grey become sandy and a coarse grit is developed in the Porter St. No. 1 Borehole[1] above 53 ft 7 in which is probably represented by the sandstones and conglomerates above 46 ft 8 inches in the Hall St. No. 1 Borehole and below 42 ft in the Hall St. No. 2 Borehole. Farther north-west, the Bottom Coal is well developed as a split seam 6 ft 7 in thick base at 2395 ft 2 inches in the Penn No. 1 Borehole (Fig. 3).

The Mealy Grey Coal is probably represented in the Kate's Hill No. 2 Borehole by inferior coal 1 ft 3 in, seatearth 3 in and inferior coal 1 ft 7 in, base at 105 ft 10 in. A 1 ft 3-in bed of dolerite, which occurs in this borehole at 107 ft 7 in, has apparently had little metamorphic effect upon the coal. About 35 ft of measures were found below the Mealy Grey Coal to the base of the Carboniferous in the Kate's Hill Nos. 2 and 3 boreholes and the Porter St. No. 1 Borehole. These measures are mainly conglomeratic grits and sandstones with carbonaceous seatearths. Primary red beds of seatearth type occur in these boreholes but were not recorded at an equivalent horizon in the Hall St. No. 1 Borehole (Plate II). The uppermost 6 in of the Silurian Lower Ludlow Shale was reddened beneath the Carboniferous unconformity in the Kate's Hill No. 3 Borehole, but elsewhere these greenish grey calcareous mudstones were unaltered (Plate II).

The structure of the Kate's Hill area

The five boreholes sunk in the Kate's Hill area by Dudley Corporation proved several errors in the previous interpretation of the geology of this structurally difficult area. The Kate's Hill area is situated at the southern extremity of the Dudley Port trough faults and is dominated by the igneous rock mass of Cawney Hill. The Kate's Hill No. 1 Borehole (Fig. 2) started in Etruria Marl facies instead of normal grey Middle Coal Measures as shown on the current published map. Dips of up to 35° were encountered in this borehole and also in the Kate's Hill Nos. 3 and 5 boreholes which average from 20° to 30°. In the Kate's Hill No. 2 Borehole, dips at 12° were recorded in the upper part and 24° in the lower part with a fault (throw about 70 ft) at 87 ft. The dip in the No. 4 Borehole was about 17°. The simplest explanation of the relationships of the rocks encountered in these boreholes is provided by the existence of two north-westerly trending faults which throw down the igneous rock of Cawney Hill. This is an extension of the Rowley Regis igneous mass to the east, where it is overlain by a small thickness of Etruria Marl facies in the Twin Quarry near Oakham (Whitehead and Pocock 1947, p. 135) thus demonstrating that it is a sill-like intrusion rather than a lava-flow. The occurrence of Etruria Marl facies in the Kate's Hill No. 1 Borehole and of Middle Coal Measures in the Kate's Hill Nos. 4 and 5 boreholes supports the view that this igneous rock is a sill-like mass intruded into Etruria Marl facies with post-intrusion faults developed on its north-east and south-west sides (Plate I) rather than an intrusion resting upon Etruria Marl facies which had previously been faulted against

[1] I am informed by Mr. C. V. Knipe, B.Sc., that the clay horizon from 25 ft 6 in to 31 ft 9 in in this borehole is represented by old workings and a 5-ft dirty coal seam in adjacent shallow boreholes. This seam, rather than the 6-in coal at 15 ft may be the Bottom Coal (Plate II).

Middle Coal Measures as shown on Whitehead's 1920 six-inch geological map.

The small faults recorded in mine workings beneath this igneous rock outcrop in the Cawney Hill–Oakham area (Whitehead and Eastwood 1927, p. 167) apparently do not affect it, possibly due to differences in competence between the Carboniferous formations which are mainly composed of clays and mudstones and the harder igneous rock. Old cross-measure sections from workings beneath the Rowley Regis dolerite show many small faults and incompetent squeezing and crushing of the measures. Some faulting was almost certainly developed prior to the intrusion of the igneous rock or at the time of its intrusion to provide the feeder channels and amounts of vertical displacement caused when the laccolitic sill changed horizon. Finally, it is notable that the temperature of intrusion of the Midland igneous sills (judged from the thermal metamorphism of the underlying and overlying rocks) does not appear to have been very high; even when these sills are over 150 ft thick, as in the Landywood area near Wolverhampton, there is little coking of the adjacent coals (although they may be rendered valueless by the loss of volatiles and the addition of carbonate replacement minerals) and hardening only extends a few feet into the host rocks. By direct contrast a fire in the old Thick Coal workings in the Dudley Dock area has thermally metamorphosed, in places to a quartzite, 45 ft of overlying Thick Coal Rock (p. 15).

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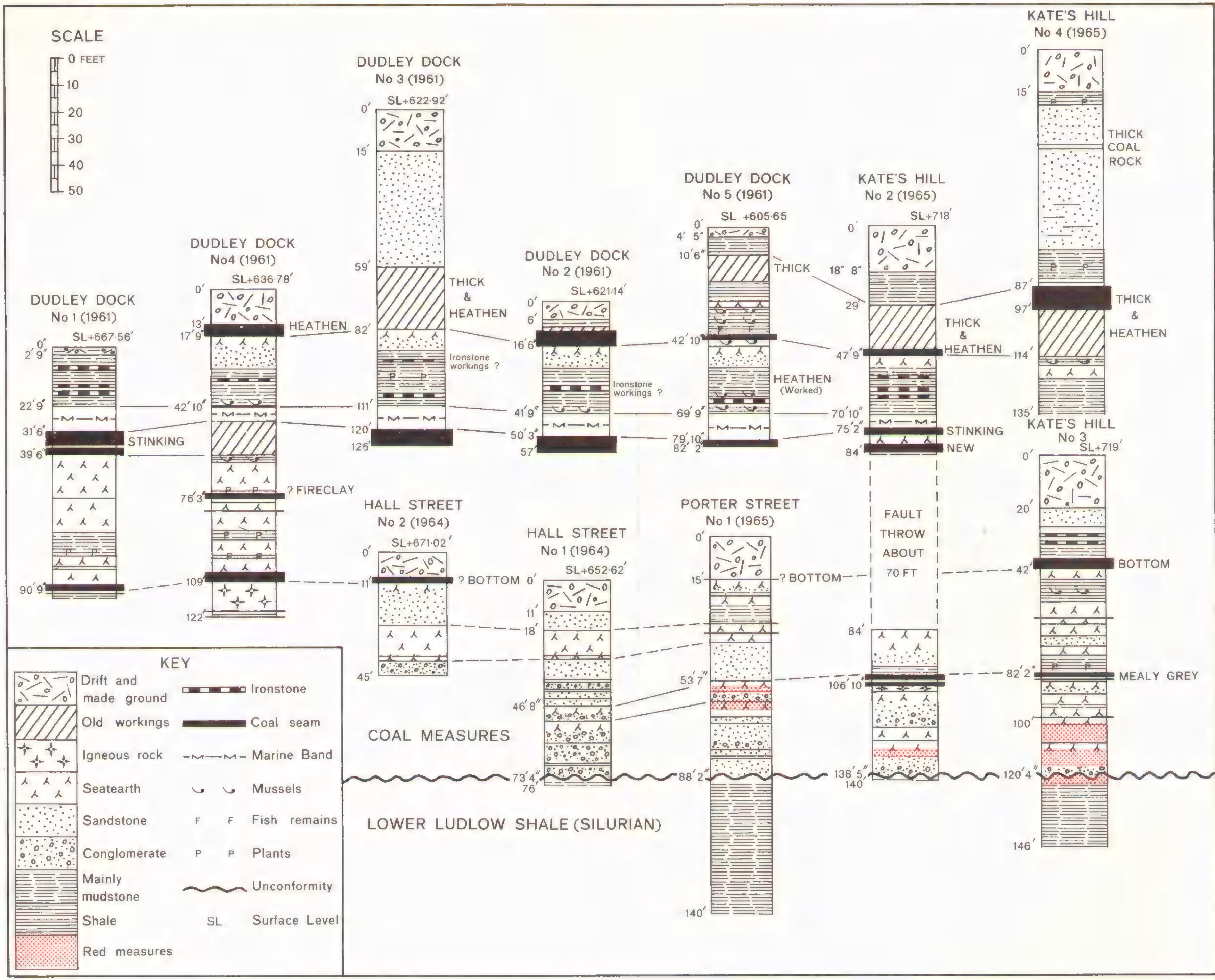
SCALE
0 FEET
10
20
30
40
50
DUDLEY DOCK No 1 (1961)
SL+667·56′
2′ 9″
22′ 9″
31′ 6″
STINKING
39′ 6″
90′ 9″
DUDLEY DOCK No4 (1961)
SL+636·78′
13′
17′ 9″
HEATHEN
42′ 10″
? FIRECLAY
76′ 3″
109′
122′
DUDLEY DOCK No 3 (1961)
SL+622·92′
15′
59′
THICK & HEATHEN
82′
Ironstone workings ?
111′
120′
125′
DUDLEY DOCK No 2 (1961)
SL+621·14′
6′
16′ 6″
Ironstone workings ?
41′ 9″
50′ 3″
57′
DUDLEY DOCK No 5 (1961)
SL +605·65
4′ 5″
10′ 6″
THICK
42′ 10″
HEATHEN (Worked)
69′ 9″
79′ 10″
82′ 2″
KATE'S HILL No 2 (1965)
SL+718′
18″ 8″
29′
THICK & HEATHEN
47′ 9″
70′ 10″
75′ 2″
STINKING
84′
NEW
FAULT THROW ABOUT 70 FT
106′ 10″
138′ 5″
140′
KATE'S HILL No 4 (1965)
15′
THICK COAL ROCK
87′
97′
THICK & HEATHEN
114′
135′
KATE'S HILL No 3
SL+719′
20′
BOTTOM
42′
82′ 2″
MEALY GREY
100′
120′ 4″
146′
HALL STREET No 2 (1964)
SL+671·02′
? BOTTOM
11′
18′
45′
HALL STREET No 1 (1964)
SL+652·62′
11′
18′
46′ 8″
73′ 4″
76′
PORTER STREET No 1 (1965)
15′
? BOTTOM
53′ 7″
88′ 2″
140′
COAL MEASURES
LOWER LUDLOW SHALE (SILURIAN)
KEY
Drift and made ground
Old workings
Igneous rock
Seatearth
Sandstone
Conglomerate
Mainly mudstone
Shale
Red measures
Ironstone
Coal seam
Marine Band
Mussels
Fish remains
Plants
Unconformity
SL Surface Level

APPENDIX

BOREHOLE RECORDS

The following logs are the more important of the records of recent boreholes in the South Staffordshire Coalfield. Some have been slightly abridged; the complete records are filed within the Institute of Geological Sciences.

Dudley Dock No. 1 Borehole (1961)

Surface Level +667·56 ft. National Grid ref. SO 9361 9024

Examined by E. G. Poole. Diamond bit cores from surface to 91 ft.

Description of Strata	*Thickness* *Ft*	*in*	*Depth* *Ft*	*in*
SUPERFICIAL DEPOSITS				
Clay, brown and grey with sandstone (*fragments and brown ironstone nodules*)	2	9	2	9
MIDDLE COAL MEASURES				
Clay, pale grey and brown mottled, soft	1	10	4	7
Mudstone, grey and brown weathering, silty in upper part becoming smoother below 6 ft with small ironstones ..	8	1	12	8
Ironstone, pale buff brown	0	2	12	10
Mudstone, grey with brown mottles, fairly soft	2	8	15	6
Mudstone, dark grey, carbonaceous, clayey	0	3	15	9
Ironstone, greyish brown, hard	0	4	16	1
Mudstone, dark grey rather smooth becoming silty with depth. Occasional ironstone nodules	3	11	20	0
Mudstone, dark grey, silty, with pyritized fucoid markings and crystals. Sporadic brown ironstone nodules ..	2	9	22	9
Stinking Marine Band. Mudstone, dark grey silty with pyritized spots and 'fucoids'. Scattered *Lingula sp.* ..	8	9	31	6
LOWER COAL MEASURES				
Stinking. Coal, dull with bright bands	5	1	36	7
Seatearth, dark, carbonaceous	0	11	37	6
Coal and coaly shale	0	6	38	0
Coal, rather inferior	1	6	39	6
Seatearth, grey and buff brown with brown ironstones and roots. Silty below 63 ft with sphaerosiderites	29	6	69	0
Mudstone, greyish brown, silty with roots and sandstone wisps	5	0	74	0
Mudstone, greyish brown, with roots and plants. Rather shaly in lower part	2	9	76	9
Seatearth, brownish grey, slightly silty, slickensided with roots and ironstones	4	3	81	0
Mudstone, black, carbonaceous, rather shaly with coal streaks and plant stems	0	6	81	6
Seatearth, dark grey and brown, rather carbonaceous ..	7	0	88	6
?Bottom. Coal, bright (*fragmentary core*)	1	0	89	6
Mudstone, black, carbonaceous with coaly streaks ..	0	6	90	0

Description of Strata	Thickness Ft	in	Depth Ft	in
Coal, bright (*fragmentary core*)	0	9	90	9
Mudstone, black, carbonaceous, shaly seatearth-type ..	0	3	91	0
Total depth ..			91	0

Dudley Dock No. 2 Borehole (1961)

Surface Level +621·41 ft. National Grid ref. SO 9357 8999

Examined by E. G. Poole. Diamond bit cores from 5 to 57 ft.

Description of Strata	Thickness Ft	in	Depth Ft	in
SUPERFICIAL DEPOSITS				
Clay, grey, weathered with ironstone fragments and mudstone fragments. Becoming carbonaceous below 10 ft ..	12	0	12	0
MIDDLE COAL MEASURES				
Heathen. Coal (*broken core*)	4	6	16	6
Shale, black with plants	0	2	16	8
Seatearth, grey, silty with roots	0	10	17	6
Sandstone, grey, fine-grained with roots and ironstones ..	1	6	19	0
Mudstone, grey, blocky, current-bedded	1	0	20	0
Sandstone, grey, fine-grained, current-bedded	0	6	20	6
Mudstone, grey, silty with limonitic patches	2	0	22	6
Sandstone, grey, fine-grained, current-bedded	4	2	26	8
Mudstone, grey, blocky, silty with sandstone wisps ..	5	4	32	0
Mudstone, grey, clayey with limonitic veins	7	2	39	2
Clay, dark grey with ironstone fragments (*probably old workings in ironstone*)	1	7	40	9
Mudstone, dark grey with mussels	0	6	41	3
Mudstone (*broken core*)	0	6	41	9
Stinking Marine Band. Mudstone, grey blocky silty with scattered brown ironstone and pyrite nodules, pyritized strap-like markings, scattered *Lingula sp.*	8	6	50	3
LOWER COAL MEASURES				
Stinking. Coal, (*broken core*), rather dirty and inferior ..	6	9	57	0
Total depth ..			57	0

Dudley Dock No. 3 Borehole (1961)

Surface Level +622·92 ft. National Grid ref. SO 9340 9013

Examined by E. G. Poole. Diamond bit cores from 15 to 126 ft.

Description of Strata	Thickness Ft	in	Depth Ft	in
SUPERFICIAL DEPOSITS				
Made ground	15	0	15	0

Description of Strata	Thickness Ft	in	Depth Ft	in
MIDDLE COAL MEASURES				
Thick Coal Rock. Sandstone, reddish brown, fine-grained, gently current-bedded, somewhat broken, metamorphically hardened. Intensely reddened at intervals along joints	44	0	59	0
Workings in **Thick** and **Heathen** coals: *No core*	10	0	69	0
Workings in **Thick** and **Heathen** coals: Clay, dark, carbonaceous with red shale fragments and ironstones. *No core from 72 to 75 ft*	13	0	82	0
Shale, black, silty, carbonaceous with roots and plants (Dip 8°)	1	0	83	0
Seatearth, pale grey, silty with roots and ironstones ..	1	6	84	6
Sandstone, pale grey, fine-grained, current-bedded with silty and carbonaceous mudstone wisps	5	0	89	6
Mudstone, grey, finely silty and micaceous. Rather smooth. Ironstone band at 93 ft 6 in to 93 ft 8 in	5	6	95	0
No core (?ironstone workings)	2	0	97	0
Mudstone, grey, silty with limonitic patches, plant fragments and sandy wisps from 100 to 102 ft	9	3	106	3
Ironstone, brownish grey, very hard	0	2	106	5
Mudstone, grey, clayey with occasional ironstones ..	3	7	110	0
Clay, grey, soft with ironstone and shale fragments. (*Lateral movement?*)	1	0	111	0
Stinking Marine Band. Mudstone, dark grey, finely silty with pyritic patches. Foraminifera at 111 ft, *Lingula sp.* at 114 ft and below with abundant pyritized strap-like markings. Shaly, soft, slickensided and clayey in places. Rather shaly and carbonaceous below 119 ft 3 in with abundant *Lingula sp.* and a half-inch band of pyrite at base	9	9	120	9
LOWER COAL MEASURES				
Stinking. Coal. Inferior, pyritic with shaly bands	5	3	126	0
Total depth ..			126	0

Dudley Dock No. 4 Borehole (1961)

Surface Level +636·78 ft. National Grid ref. SO 9352 9012

Examined by E. G. Poole. Diamond bit cores from surface to 122 ft.

Description of Strata	Thickness Ft	in	Depth Ft	in
SUPERFICIAL DEPOSITS				
Made ground, clay matrix with glass, bricks, cinders and ashes	13	0	13	0
MIDDLE COAL MEASURES				
Heathen. Coal (*broken core*), thin dirt bands	4	9	17	9
Mudstone, dark, carbonaceous, silty with many roots and plants	0	9	18	6

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Seatearth, pale grey, silty with many roots. Becoming finely sandy with brown ironstones	2	4	20	10
Sandstone, pale grey with thin carbonaceous wisps	1	6	22	4
Mudstone, grey, blocky, silty with sandstone wisps and bands. (Dip 10° at 24 ft)	4	2	26	6
Mudstone, grey, blocky, silty with sandy patches. Brown lenticular ironstones	7	6	34	0
Ironstone, brown, hard	0	3	34	3
Mudstone, grey, silty, finer grained with depth	4	3	38	6
Clay, dark with slickensided mudstone fragments	2	0	40	6
Mudstone, dark grey, silty with pyritized mussels	1	6	42	0
Ironstone, brown, hard with ankerite veins	0	2	42	2
Mudstone, dark grey, soft, with brown ironstones	0	8	42	10
Stinking Marine Band. Mudstone, dark grey, soft, clayey with foraminifera and pyritized strap-like markings. Ironstone from 43 ft 10 in to 44 ft. (*Badly broken below 49 ft—collapsed roof measures*)	12	8	55	6
LOWER COAL MEASURES				
Stinking. (*Worked out.*) Clay with coal fragments mudstone and pyrite	7	4	62	10
Ironstone	0	2	63	0
Mudstone, dark grey, shaly with mussels and fish debris	0	4	63	4
Mudstone, dark, shaly with ironstone (*broken core*)	0	6	63	10
Mudstone, brownish grey, sideritic with plants and sphaerosiderites	0	6	64	4
Mudstone, brownish grey, rather carbonaceous with roots	1	1	65	5
Clay, soft, brownish grey	1	2	66	7
No core (*could be anywhere below 63 ft 4 in*)	4	5	70	0
Seatearth, brown with roots, soft and slickensided	0	8	70	8
Mudstone, brownish green, silty becoming finely sandy, hard, sideritic with roots and ironstones	1	7	72	3
Mudstone, dark greyish brown, carbonaceous with sandy wisps, roots, plants and many megaspores	0	7	72	10
Mudstone, brownish grey, silty, plant-rich	1	11	74	9
?Fireclay. Coal, rather inferior	0	7	75	4
Coal, bright	0	5	75	9
Coal, rather inferior	0	6	76	3
Mudstone, carbonaceous, coaly with plants and megaspores	0	11	77	2
Seatearth, brown, iron-rich with roots	1	0	78	2
Sandstone, whitish grey, medium-grained	1	0	79	2
Clay, black, soft	0	2	79	4
No core (*could be missing anywhere below 70 ft*)	0	8	80	0
Coal and dirt	0	3	80	3
Seatearth, brown hard, sandy with sphaerosiderites	8	0	88	3
Mudstone, grey, silty, sideritic with plants and ironstones	1	11	90	2
Seatearth, brown, silty, iron-rich with many ironstones	7	6	97	8
Mudstone, greyish brown with plant and roots	0	5	98	1
Shale, black, carbonaceous with plants	0	1	98	2
Seatearth, brown, iron-rich with roots. Dark, shaly and highly carbonaceous below 104 ft	7	10	106	0

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
?**Bottom.** **Coal** (*core*), thermally metamorphosed, much cleat	1	0	107	0
Coal (*fragments*), much cleat	2	0	109	0
Dolerite, green and yellowish brown, fine-grained with much ankerite. Broken and jointed. Rafted coaly band at 117 ft 4 in	10	2	119	2
Shale, coaly, thermally metamorphosed, hard and heavy	0	5	119	7
Mudstone, carbonaceous with hematite on joints	0	11	120	6
Coal, thermally metamorphosed with much ankerite	0	3	120	9
Dolerite, pale greenish brown, fine-grained	0	6	121	3
Coal, thermally metamorphosed, hard and heavy	0	2	121	5
Mudstone, dark grey, carbonaceous, metamorphosed, hard and heavy	0	7	122	0
Total depth			122	0

Dudley Dock No. 5 Borehole (1961)

Surface Level +605·65 ft. National Grid ref. SO 9378 8985

Examined by E. G. Poole. Diamond bit cores from surface to 82 ft.

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
SUPERFICIAL DEPOSITS				
Made ground	4	5	4	5
MIDDLE COAL MEASURES				
Clay, grey, soft (weathered mudstone)	3	7	8	0
Mudstone, dark grey, silty, carbonaceous with clay bands	2	0	10	0
Mudstone, grey, silty, hard, sideritic	0	6	10	6
Thick (*worked out*), clay, reddish brown and dark grey, burnt (*no core 10 ft 9 in to 13 ft 6 in*) and cindery	11	4	21	10
Shale, black, coaly with burnt patches (*fragmentary core*)	9	2	31	0
Seatearth, brown, burnt	1	0	32	0
Shale, black, carbonaceous, plant-rich (*fragments*)	2	0	34	0
Shale, black, silty with thin-shelled mussels	0	9	34	9
Mudstone, reddish brown, hard, cindery and burnt	2	9	37	6
Shale, black, carbonaceous, silty with fish debris (*fragments*)	1	0	38	6
Heathen (*old workings*), red, hard, burnt mudstone, shale and cinder fragments	1	10	41	0
Coal, rather inferior (*fragmentary core*)	1	10	42	10
Shale, coaly	0	6	43	4
Mudstone, dark grey rather carbonaceous with mussels and ironstones	1	8	45	0
Seatearth, grey, rooty, clayey in lower part	1	0	46	0
Mudstone, grey, blocky, silty with roots and sandy wisps	1	0	47	0
Sandstone, pale grey, fine-grained with carbonaceous wisps	5	8	52	8
Mudstone, grey, silty with thin current-bedded sandstone wisps and occasional ironstone bands	8	4	61	0
Mudstone, dark grey, softer with ironstones. Scattered mussels	4	4	65	4
Ironstone, brown, hard	0	3	65	7

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Mudstone, dark grey, shaly, pyritic with a few mussels ..	4	1	69	6
Ironstone, brown hard	0	3	69	9
Stinking Marine Band. Mudstone, grey, silty, soft, clayey and slickensided with abundant 'fucoids' in upper part and scattered *Lingula sp.* below 74 ft 3 in	10	1	79	10
LOWER COAL MEASURES				
Stinking. Coal, (*core*), rather inferior	2	2	82	0
Total depth ..			82	0

Hall Street No. 1 Borehole (1964)

Surface level +652·62 ft. National Grid ref. SO 9462 9510

Examined by B. E. Poole. Samples to 28 ft, diamond bit cores to 76 ft.

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
SUPERFICIAL DEPOSITS				
Made ground, grey and brown sandy clay with coal, cinders and sandstone fragments	11	0	11	0
LOWER COAL MEASURES				
Clay, grey, sandy with sandstone fragments .. at	13 to 14			
Sandstone, pale grey .. .. at	17 to 18			
Clay, grey with fragments of seatearth .. .. at	18½ to 19			
Clay, as above .. .. at	21 to 22			
Clay, as above .. .. at	24 to 25			
Mudstone, grey, silty .. .. at	27 to 28			
Mudstone, grey, silty becoming sandy with depth; scattered roots	0	9	82	9
Sandstone, pale grey, fine-grained to 33 ft 7 in, coarser downwards with coaly plant fragments	8	8	37	5
Sandstone, pale grey, fine-grained with silty mudstone bands	0	5½	37	10½
Sandstone, pale grey, medium-grained becoming coarse, gritty and conglomeratic below 38 ft 8 in	2	7½	40	6
Mudstone, grey, silty with sandy bands, plant remains and rootlets	0	7	41	1
Sandstone, pale grey, fine-grained with silty mudstone bands	2	10	43	11
Mudstone, grey, silty	1	4	45	3
Sandstone, pale grey, argillaceous	0	6	45	9
Mudstone, grey, silty and sandy with comminuted plant fragments	2	9	48	6
Seatearth, dark greyish brown becoming silty below 48 ft	0	10	49	4
Sandstone, pale grey, medium-grained, becoming coarse and conglomeratic below 51 ft 5 in	3	4	52	8
Seatearth, greyish brown, silty below 53 ft 6 in	1	1	53	9
Sandstone, grey, fine-grained with silty mudstone bands ..	1	11	55	8
Sandstone, pale grey, medium-grained with small pebbles and pellets	4	4	60	0

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Sandstone, pale grey, coarse-grained, conglomeratic ..	9	0	69	0
Mudstone, grey, silty with fine-grained sandstone bands ..	1	6	70	6
Sandstone, grey, fine-grained, argillaceous becoming coarse-grained and conglomeratic below 73 ft ..	2	10	73	4
SILURIAN (LOWER LUDLOW SHALE)				
Mudstone, grey with a greenish tinge in places. Hard; calcareous bands at intervals. Scattered fossils, some pyritized	2	8	76	0
Total depth ..			76	0

Hall Street No. 2 Borehole (1964)

Surface level +671·02 ft. National Grid ref. SO 9457 9520

Examined by B. E. Poole. Samples at intervals to 48 ft.

Description of Strata		Depth Ft	Depth in
SUPERFICIAL DEPOSITS			
Made ground, bricks, cinders, pebbles and brown clay	at	5	0
Clay, grey and brown with sandstone fragments	at	8	0
Clay, dark grey, carbonaceous with coal fragments	at	11	0
LOWER COAL MEASURES			
Coal	at	13	6
Sandstone, pale grey, fine-grained, argillaceous, rooty	at	15	0
Sandstone, as above	at	18	0
Sandstone, pale grey, fine-grained	at	21	0
Sandstone, pale grey, fine-grained with abundant carbonaceous wisps	at	24	0
Sandstone, grey, banded, very muddy	at	27	0
Seatearth, greyish brown	at	30	0
Seatearth, as above, becoming silty	at	33	0
Seatearth, as above with listric surfaces	at	39	0
Mudstone, grey, silty with scattered roots	at	42	0
Sandstone, grey, medium-grained	at	43	0
Conglomerate	at	48	0
Total depth ..		48	0

Hall Street No. 3 Borehole (1964)

Surface level +674·10 ft. National Grid ref. SO 9463 9532

Examined by B. E. Poole. Samples at intervals to 42 ft.

Description of Strata		Depth Ft	Depth in
SUPERFICIAL DEPOSITS			
Made ground, sandy clay with brick and sandstone fragments ..	at	2	0
		4	0
		7	0

Description of Strata		Depth Ft	in
Lower Coal Measures			
Sandstone, coarse-grained, iron-rich	at	9	0
Clay, grey, yellow and red mottled	at	12	6
Mudstone, grey, silty with plant remains	at	15	6
Mudstone, grey, sandy	at	18	0
Mudstone, grey, sandy	at	21	0
Seatearth, pale grey	at	25	0
Mudstone, greenish grey, silty	at	30	0
Siltstone, grey, calcareous	at	42	0

Hamstead No. 1 Borehole (1948–9)

Surface level +527·0 ft. National Grid ref. SP 0759 9626

Examined by G. H. Mitchell and L. S. O. Morris. Samples to 1800 ft, diamond bit cores from 1800 to 1820 ft, 1983 to 1986 ft, 2187 to 2205 ft, 2242 to 2252 ft, 2282 to 2292 ft, 2322 to 2332 ft, 2362 to 2372 ft, 2404 to 2887 ft, 2917 to 2926 ft, 3014 to 3021 ft, 3049 to 3054 ft and 3106 to 3114 ft.

Description of Strata	Thickness Ft	in	Depth Ft	in
Drift				
Red sand and coarse gravel	50	0	50	0
BUNTER PEBBLE BEDS				
Brown and red sandstones with conglomeratic bands	390	0	440	0
Upper Coal Measures				
ENVILLE BEDS?				
Red marl and sandy marl with sandstones. Conglomeratic bands at 670 to 700 ft, 810 to 830 ft, 880 to 900 ft and 1050 to 1070 ft. Impure purple limestone fragments at 1020 to 1050 ft	630	0	1070	0
KEELE BEDS?				
Red, purple and grey marl and sandy marl. Impure purplish red limestone fragments at 1470 to 1480 ft, 1700 to 1730 ft and 1740 to 1790 ft	790	0	1860	0
HALESOWEN BEDS?				
Purple and red conglomerate from 1860 to 1870 ft on purple, grey and chocolate mudstones and sandstones. Coarse grey and green espley and conglomerate 2090 to 2110 ft on brown and grey sandy mudstones and sandstone	379	0	2239	0
ETRURIA MARL (*continuous cores from 2404 ft*)				
Brown, yellow and grey mottled mudstones with thin bands of green, purple and grey breccia	165	0	2404	0
Sandstone, greyish green, hard	3	0	2407	0
Mudstone, grey, hard, unbedded seatearth type	3	0	2410	0
Mudstone, grey, softer, unbedded seatearth type	3	0	2413	0
Mudstone, greenish grey and purple, hard, silty	4	0	2417	0
Mudstone, red and green mottled, hard, gritty, darker grey below 2423 ft	9	0	2426	0

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
MIDDLE COAL MEASURES				
Seatearth, dark grey, harder below 2429 ft	4	0	2430	0
Mudstone, grey, hard	3	0	2433	0
Shale, grey with plant remains	1	0	2434	0
Seatearth, grey, hard with sphaerosiderites	2	0	2436	0
Seatearth, dark grey, soft	3	0	2439	0
Shale, black, coaly with plant remains	1	0	2440	0
Coal	2	0	2442	0
Seatearth, grey to black	4	6	2446	6
Coal	1	0	2447	6
Seatearth, dark grey, hard with ironstone nodules	3	6	2451	0
Charles Marine Band. Shale, black with plant fragments and *Lingula sp.*	4	0	2455	0
Seatearth, grey, soft with ironstone nodules; harder below 2458 ft with sphaerosiderites	11	0	2466	0
Mudstone, grey, hard with sphaerosiderites	2	0	2468	0
Sandstone, pale grey, hard	4	0	2472	0
Mudstone, grey, hard, sandy	1	0	2473	0
Mudstone, grey and red mottled, soft and gritty	2	0	2475	0
Seatearth, dark grey with red mottles to 2479 ft	9	0	2484	0
Ironstone, dark grey, gritty	1	0	2485	0
Seatearth, grey, soft with ironstones below 2490 ft	8	0	2493	0
Shale, dark grey, carbonaceous with thin bands of inferior coal; many plants	4	0	2497	0
Seatearth, grey, hard	4	0	2501	0
Shale, black, carbonaceous with many plants	2	0	2503	0
Seatearth, black, carbonaceous	3	0	2506	0
Mudstone, black with thin coaly bands	2	6	2508	6
Shale, black, carbonaceous, hard with ironstone band at base	3	6	2512	0
Brooch. Coal	1	0	2513	0
Shale, black, carbonaceous	6	0	2519	0
Mudstone, grey with ironstone nodules	3	0	2522	0
Sub-Brooch Marine Band. Mudstone, grey with ironstone nodules, *Lingula sp.* and 'fucoids'	5	0	2527	0
Mudstone, grey, smooth, shaly with pyritized tubes	3	0	2530	0
Herring. Coal	2	0	2532	0
Seatearth, dark grey	1	3	2533	3
Coal	1	0	2534	3
Seatearth, dark grey	1	9	2536	0
Mudstone, grey, hard with abundant plant remains	9	0	2545	0
Seatearth, dark grey, soft	1	0	2546	0
Coal, bright	1	0	2547	0
Mudstone, grey, hard, with ironstones and plant remains	5	0	2552	0
Mudstone, grey hard with silty bands and occasional plant remains	28	6	2580	6
Shale, black, hard with mussels below 2582 ft and fish remains	11	6	2592	0
Mudstone, grey, shaly with mussels at 2592 ft 6 in to 2593 ft	5	9	2597	9
Thick. Coal (*fragmentary core*)	16	9	2614	6
Seatearth, dark grey, hard becoming soft with depth	3	6	2617	9
Coal, inferior	4	9	2622	6

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Seatearth, grey, hard, sandy	3	3	2625	9
Coal	2	6	2628	3
Seatearth	1	6	2629	9
Coal	4	0	2633	9
Seatearth, grey, hard, sandy	4	3	2638	0
Mudstone, grey, hard, micaceous with ironstone nodules and plant remains	8	6	2646	6
Mudstone, grey, finely micaceous, shaly with fish remains	1	0	2647	6
Seatearth, dark grey, soft	3	6	2651	0
Coal	1	6	2652	6
Seatearth, grey, ganisteroid	8	6	2661	0
Mudstone, grey, finely micaceous with sandy bands and plant remains	22	0	2683	0
Mudstone, grey, hard, with ironstone nodules and plant remains	16	0	2699	0
Coal	2	0	2701	0
Seatearth, grey, hard, sandy with ironstones	5	0	2706	0
Shale, grey, sandy with plants and ironstones	3	0	2709	0
Sandstone, pale grey, very hard, fine-grained with plants	4	0	2713	0
Mudstone, dark grey with ironstones and mussels	1	0	2714	0
Shale, dark grey, canneloid with fish fragments	1	4	2715	4
Coal	0	2	2715	6
Shale, black, carbonaceous with ironstone	0	6	2716	0
Seatearth, grey, hard, sandy with ironstones	9	0	2725	0
Sandstone, pale grey, with shaly mudstone bands	6	0	2731	0
Mudstone, grey, hard with ironstones; fish fragments at 2738 ft	8	0	2739	0
Stinking Marine Band. Mudstone, dark grey, hard, well bedded with ironstone nodules, plants and *Lingula sp.*	23	0	2762	0
LOWER COAL MEASURES				
Mudstone, dark grey, hard and well bedded	5	0	2767	0
Seatearth, brownish grey, soft	2	0	2769	0
Seatearth, black, shaly	1	0	2770	0
Stinking Coal.	2	6	2772	6
Seatearth, brownish grey, soft	2	0	2774	6
Coal	2	0	2776	6
Seatearth, black, coaly	0	6	2777	0
Seatearth, brown, hard, sandy	0	6	2777	6
Ganister, pale grey, hard, fine-grained	4	0	2781	6
Sandstone, pale grey, fine-grained, becoming coarser below 2785 ft with green mudstone and coaly plant fragments	10	6	2792	0
Sandstone, pale grey, fine-grained passing into coarse white ganister below 2795 ft	5	0	2797	0
Seatearth, dark grey, carbonaceous; paler grey and silty with ironstone nodules below 2798 ft	10	0	2807	0
Shale, black, carbonaceous	1	0	2808	0
Seatearth, dark grey, carbonaceous, slightly silty	1	0	2809	0
Seatearth, grey with roots	8	0	2817	0
Mudstone, grey becoming silty below 2818 ft; plants and ironstone bands	4	0	2821	0
Seatearth, dark grey, soft with plants	1	0	2822	0

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Shale, black, carbonaceous with plants	0	6	2822	6
Seatearth, grey, soft with ironstones, becoming hard and silty between 2826 and 2835 ft	15	0	2837	6
Coal, inferior (*fragmentary core*)	3	6	2841	0
Seatearth, dark green, soft with coaly bands	8	0	2849	0
Coal (*fragmentary core*)	0	4	2849	4
Seatearth, pale grey becoming darker and sandy below 2856 ft	8	8	2858	0
Shale, dark grey, carbonaceous with plant debris	1	0	2859	0
Coal, inferior	1	0	2860	0
Sandstone, grey, turbulently bedded with plants	0	4	2860	4
Coal, inferior	0	6	2860	10
Seatearth, dark grey with sphaerosiderites	0	6	2861	4
Sandstone, grey, fine-grained with coarser bands, turbulently bedded with *Calamites sp.* at 2863 ft	3	11	2865	3
Ironstone, brown with ankerite veins	0	9	2866	0
Seatearth, pale grey, sandy with sphaerosiderites	8	0	2874	0
Shale, dark, carbonaceous with bands of seatearth	2	0	2876	0
Ganister, grey, fine-grained, turbulently bedded	1	6	2877	6
Sandstone, grey, hard with ironstone	3	6	2881	0
Mudstone, dark grey with plants and sandy bands	4	0	2885	0
Ironstone, dark brown with sandy wisps	1	0	2886	0
Mudstone, greyish green with plants and ironstones	1	0	2887	0
Mudstone, dark grey, with sandy bands (*no core*)	30	0	2917	0
Mudstone, grey with ironstone bands	9	0	2926	0
Mudstone, grey with bands of conglomerate (*no core*)	30	0	2956	0
Shale, dark grey (*no core*)	22	0	2978	0
Seatearth, grey (*no core*)	12	0	2990	0
Shale, dark grey (*no core*)	15	0	3005	0
Shale, grey (*no core*)	6	0	3011	0
Mudstone, dark grey with *Neuropteris sp.*	3	0	3014	0
Shale, black carbonaceous	0	6	3014	6
Mudstone, dark grey, sandy	1	0	3015	6
Sandstone, greenish grey coarse grit with bands of pebbles	5	6	3021	0
Mudstone, grey (*no core*)	8	0	3029	0
Conglomerate (*no core*)	6	0	3035	0
SILURIAN				
Mudstone, grey (*no core*)	14	0	3049	0
Mudstone, greenish grey, calcareous with fossils	5	0	3054	0
Mudstone, grey (*no core*)	52	0	3106	0
Mudstone, greenish grey, calcareous with thin limestone partings and bands of fossils	8	0	3114	0
Total depth			3114	0

Kate's Hill No. 1 Borehole (1965)

Surface level about 727 ft. National Grid ref. SO 9522 8991
Examined by E. G. Poole. Diamond bit cores from 16 to 201 ft.

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
SUPERFICIAL DEPOSITS				
Not seen (*no cores*)	16	0	16	0
Made ground, purple clay with a dolerite pebble	1	0	17	0

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
UPPER COAL MEASURES (ETRURIA MARL)				
Mudstone purplish brown and yellow mottled, very soft seatearth type, slickensided with occasional bands of purple mottling	3	8	20	8
Mudstone, purple and yellow mottled slickensided seat-earth type with greenish grey patches.	1	4	22	0
Mudstone purple, brown and yellow mottled and veined, small slickensides, unbedded seatearth type, finely silty and micaceous	2	6	24	6
Sandstone, brown and green mottled fine to medium-grained finely micaceous with a marly matrix ..	0	10	25	4
Mudstone, purple and yellow mottled with greenish grey patches, poorly bedded, slickensided	0	6	25	10
Mudstone, purple and lilac, silty, finely micaceous, poorly bedded	0	7	26	5
Mudstone, purple and grey mottled, highly slickensided, soft, clayey	0	4	26	9
Clay, dark grey to black, carbonaceous	0	1	26	10
Clay, dark grey, soft, highly slickensided	0	2	27	0
Mudstone, purple tinged grey with black carbonaceous patches, plant fragments, slickensides, silty, finely micaceous; predominantly greenish grey below 27 ft 3 in	3	6	30	6
Mudstone, brownish grey, soft, clayey highly slickensided	0	7	31	1
Clay, black, highly carbonaceous, soft slickensided ..	0	5	31	6
Mudstone, dark grey seatearth type, slickensided; scattered roots, fairly soft, paler grey below 33 ft and becoming slightly silty	2	6	34	0
Mudstone, grey and purple mottled, fairly soft, slicken-sided, unbedded, predominantly purple below 35 ft with grey mottles below 35 ft 6 in	2	0	36	0
Mudstone, purple and grey mottled, blocky, unbedded, silty, finely micaceous	1	0	37	0
Espley grit, pink, grey, purple and green gritty fragments with small pebbles in a soft greenish grey mud-flake matrix	0	10	37	10
Mudstone, purple and grey, soft slickensided with gritty fragments and green angular mudstone fragments ..	0	2	38	0
Espley grit (*fragmentary core*) colours as before with green mudstone fragments	1	10	39	10
Mudstone, purple, silty, micaceous. Scattered carbona-ceous root fragments	0	2	40	0
Espley grit, green muddy matrix, dark green mud flakes and small gritty grains	0	6	40	6
Mudstone, greenish grey, silty, poorly bedded	0	4	40	10
Espley grit, brown and grey matrix with dark green mudstone fragments, green, brown and purple gritty grains	0	6	41	4
Mudstone, grey, unbedded, slightly silty, yellowish brown and purple patches; becoming softer and clayey below 43 ft 2 in	2	8	44	0
Mudstone, dark grey, silty, blocky, micaceous; scattered carbonaceous plant fragments and thin coaly films ..	1	3	45	3

Description of Strata	*Thickness* Ft	*Thickness* in	*Depth* Ft	*Depth* in
Mudstone, seatearth, dark grey, blocky, silty, scattered roots, slickensides	1	9	47	0
Mudstone, paler grey, faintly purple tinged with few red mottles, blocky unbedded, silty, finely micaceous becoming purple and green mottled below 49 ft ..	2	9	49	9
Mudstone, reddish purple and grey, soft slickensided and clayey	0	3	50	0
Mudstone, purple and grey, unbedded (*fragmentary core*)	2	0	52	0
Clay, yellowish brown with green espley grit fragments ..	0	6	52	6
Mudstone, purple and grey mottled, unbedded, slightly silty (*fragmentary core*)	3	9	56	3
Mudstone, dark grey rather carbonaceous, soft clayey and highly slickensided	0	10	57	1
Seatearth, brownish grey, silty, blocky, unbedded with roots, slickensides; greenish grey below 58 ft with purple mottles	4	5	61	6
Mudstone, purple, green and brown mottled, unbedded seatearth-type, soft, slickensided and clayey	1	6	63	0
Mudstone, black, highly slickensided, soft and clayey ..	0	2	63	2
Seatearth, dark grey and brown, clayey with roots, slickensides	0	10	64	0
Mudstone, greenish grey with brown mottles, blocky, silty, unbedded with scattered roots. Purple mottles below 68 ft, slip plane at 71 ft 3 in to 71 ft 10½ in ..	7	3	71	3
(60° hade)	0	7½	71	10½
Mudstone, dark greenish grey, slickensided; black carbonaceous patches	0	11½	72	9
Mudstone, dark grey and dark green mottled, blocky, silty, unbedded seatearth type	2	3	75	0
Mudstone, as above with occasional red mottles below 76 ft 2 in and scattered roots	3	10	78	10
MIDDLE COAL MEASURES				
Mudstone, dark grey, poorly bedded, finely micaceous with slickensides and occasional roots; becoming slightly silty below 80 ft 2 in	3	8	82	6
Mudstone, dark grey, highly carbonaceous, soft and clayey, highly slickensided; predominantly dark brownish grey below 82 ft 8 in with a black carbonaceous band in lowest ½ in	0	9	83	3
Mudstone, pale grey seatearth type, soft clayey and rooty	0	9	84	0
Mudstone, dark grey, blocky, poorly bedded, finely micaceous, slightly silty with ironstones	1	0	85	0
Mudstone, paler grey, blocky, silty, micaceous, few roots (Dip 20° at 86 ft 6 in) darker grey in lower part ..	1	6	86	6
Sandstone, brownish grey, fine grained	0	5	86	11
Mudstone, dark grey, silty and micaceous. Plants including *Lepidodendron*	0	7	87	6
Mudstone, dark grey, clayey, highly slickensided and crushed	0	5	87	11
Coal, hard bright	0	1	88	0
Cavings, mudstone, clay	0	6	88	6
Coaly mudstone	0	1	88	7

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Mudstone (*fragments*) coaly, black, highly carbonaceous, soft crushed, highly slickensided, clayey . .	0	10	89	5
Clay, dark grey and black, highly carbonaceous, slickensided along bedding	1	7	91	0
Mudstone, dark grey and dark brown, poorly bedded, seatearth type, soft and clayey with scattered rootlets	1	6	92	6
Mudstone, grey, blocky, slightly silty, slickensided, poorly bedded	3	0	95	6
Mudstone, as above	0	6	96	0
Mudstone, black, highly carbonaceous, clayey highly slickensided and possibly faulted	1	0	97	0
Missing core	1	6	98	6
Mudstone, black, finely silty and micaceous, bedded, broken and slickensided, small pyrite crystals, scattered fish remains, tubes or roots penetrating core, coal fragments (might be cavings) at 99 ft 6 in	1	0	99	6
Mudstone, black, finely silty and micaceous, well bedded; scattered fish remains. Highly slickensided and broken below 100 ft 2 in	2	0	101	6
Brooch. Coal (*good core*)	0	10	102	4
Mudstone, black highly carbonaceous with coaly wisps	0	6	102	10
Coal (*good core*), mainly bright with occasional dull bands	4	8	107	6
Coal mainly bright (Dip 20°)	1	0	108	6
Mudstone, dark grey to black highly carbonaceous with many roots	1	8	110	2
Mudstone, black canneloid, fissile, splintery sub-conchoidal fracture, finely disseminated pyrite, slickensided basal bedding plane	0	10	111	0
Mudstone, grey, blocky, silty with sandy wisps; fairly abundant roots in upper part	2	6	113	6
Mudstone, dark grey, silty, micaceous with thin sandstone wisps at intervals. A few roots in upper part; brown iron-rich nodules and patches; dark carbonaceous wisps	2	0	115	6
Mudstone, dark grey, finely silty, micaceous with carbonaceous plant fragments (Dip 30°). A few sandy wisps in upper part. Softer with much slickensiding of bedding planes	3	2	118	8
Ironstone, brown, hard, splintery	0	2	118	10
Mudstone, dark grey, silty, micaceous with occasional sandy patches and dark carbonaceous wisps. Slickensided bedding planes	1	1	119	11
Ironstone, brown, hard, splintery with plants	0	1	120	0
Mudstone, dark grey, fairly smooth. Badly crushed with much slickensiding (Dip 30°–35°.) (*Fragmentary core from 122 ft 6 in to 124 ft 6 in*)	4	6	124	6
Mudstone, dark grey, silty, micaceous with occasional plant fragments	1	2	125	8
Sub-Brooch Marine Band. Mudstone, dark grey fairly smooth with brown iron-rich areas; small pittings and micro-fossils. Small pyritized areas; *Lingula sp.* [large] at 126 ft 3 in and 127 ft 10 in. Worm trails and many pittings below 128 ft. Badly crushed and slickensided throughout	2	10	128	6

Description of Strata	Thickness Ft	in	Depth Ft	in
Mudstone, dark, carbonaceous with coaly wisps. (*Slickensided fragmentary core*)	0	3	125	9
Herring. Coal (*part fragmentary core*)	2	8	131	5
Mudstone, dark grey, carbonaceous	0	2	131	7
Coal, mainly bright (*core and fragments*)	0	6	132	1
Mudstone, dark highly carbonaceous with thin beds of black seatearth, coaly plant-rich shaly bands and pyritized areas	0	11	133	0
Coal, bright with dull bands (*part fragmentary core*) ..	1	9	134	9
Mudstone, black, heavy, with roots	0	3	135	0
Seatearth, brown, soft, highly slickensided (*fragmentary core*)	3	0	138	0
Mudstone, grey, finely silty, soft, wet and clayey ..	1	10	139	10
Seatearth, brown, soft, slickensided with roots. (*Cavings mixed with core in places*)	2	7	142	5
Coal, inferior with dirt bands	2	7	145	0
Seatearth mudstone, black, highly carbonaceous, soft and clayey in upper part, harder and more fissile with depth; thin coaly shale partings	2	4	147	4
Seatearth, brown blocky, slickensided, unbedded with many roots. Dark brownish grey below 149 ft, soft and clayey at 152 ft 2 in to 152 ft 11 in	3	8	151	0
Mudstone, brown, hard, heavy, iron-rich silty with roots ..	1	0	152	0
Mudstone, dark grey and brown mottled, hard, blocky, silty and micaceous with scattered roots. Thin sandstone bands below 153 ft	3	0	155	0
Sandstone, pale grey, fine-grained with dark carbonaceous wisps	0	4	155	4
Mudstone, dark grey, silty, micaceous with thin bands of ironstone and many plants	0	11	156	3
Mudstone, dark grey with thin paler grey medium-grained sandstone wisps and many plant fragments and stems ..	0	11	157	2
Sandstone, brownish grey, medium-grained with dark, current-bedded, sandy mudstone wisps in upper part; becoming very coarse-grained and gritty below 159 ft with small green mudstone fragments ('cat-brain'). Sharp erosive base	2	10	160	0
Mudstone, dark grey, silty, micaceous with plant fragments becoming abundant in lower part. Brown, iron-rich bands and slickensided bedding planes	6	0	166	0
Coaly shale, black with slickensided bedding planes. Plant-rich	0	6	166	6
Seatearth, black, shaly with slickensided bedding planes. Many roots. Soft and clayey in part	1	5	167	11
Coaly shale, black with slickensided bedding planes and plants	0	5	168	4
Coal, inferior	0	8	169	0
Mudstone, black, carbonaceous	0	1	169	1
Dolerite, pale greenish grey fine-grained with black and white porphyritic crystals and pyrite	1	9	170	10
Coal, heavy inferior with much 'cleat' in upper part ..	0	10	171	8
Mudstone, black, carbonaceous with coaly streaks ..	0	3	171	11
Seatearth, dark greyish brown, soft and clayey with roots and slickensides	3	7	175	6

Description of Strata	Thickness Ft	in	Depth Ft	in
Mudstone, brownish grey, silty, micaceous with roots and brown iron-rich patches	2	6	178	0
Mudstone, dark grey, carbonaceous with roots and slickensided shaly bedding planes	0	9	178	9
Mudstone, brown, harder, iron-rich with plants, megaspores and roots	0	3	179	0
Mudstone, dark grey with brown patches, softer, slickensided with roots and plants	1	0	180	0
Coaly shale	0	7	180	7
Mudstone, dark grey and brown; rooty slickensided, shaly seatearth type	0	11	181	6
Coal, inferior with dirt bands (*core*)	0	6	182	0
Carbonaceous mudstone, black, rooty	0	2	182	2
Coal, inferior (*fragmentary core*)	0	4	182	6
Seatearth, dark brownish grey, soft, slickensided in upper part becoming hard, heavy and iron-rich below 183 ft 9 in	2	6	185	0
Mudstone, seatearth type, brown and dark grey mottled, silty, blocky, slickensided with many roots. Becoming shaly below 188 ft with plant stems	5	9	190	9
Ironstone, brown, hard, splintery with white ankerite veins	0	6	191	3
Mudstone, dark grey, silty, micaceous with many roots. Brown ironstone nodules and patches	0	6	191	9
Mudstone, dark brownish grey, silty with iron-rich areas. Scattered plant stems in upper part, abundant plants and becoming highly carbonaceous in lower part ..	0	11	192	8
Sandstone, brownish grey, medium-grained, current-bedded with carbonaceous wisps rich in plant debris ..	3	3	195	11
Seatearth, brownish grey, soft and clayey becoming black and carbonaceous below 196 ft 6 in	1	11	197	10
Seatearth, brown, blocky with roots	0	6	198	4
Sandstone, brownish grey, fine-grained argillaceous with mudstone bands. Iron-rich with many roots	0	6	198	10
Mudstone, brownish grey, silty with roots..	1	1	199	11
Sandstone, whitish grey, rather coarse-grained with green mudstone fragments and coarse gritty grains	1	2	201	0
Total depth ..			201	0

Kate's Hill No. 2 Borehole (1965)

Surface level +718 ft. National Grid ref. SO 9507 8994

Examined by E. G. Poole. Diamond bit cores from 15 to 140 ft.

Description of Strata	Thickness Ft	in	Depth Ft	in
SUPERFICIAL DEPOSITS				
Not seen (*no cores*)	15	0	15	0
Made ground, yellowish brown sandy clay with brick, tile, Coal Measures fragments and a dolerite boulder at the base	3	8	18	8

Description of Strata	*Thickness* *Ft*	*in*	*Depth* *Ft*	*in*
MIDDLE COAL MEASURES				
Sandstone, brownish weathering and grey, fine-grained, rather argillaceous with dark shaly carbonaceous wisps	1	11	20	7
Mudstone, grey with faint yellowish brown weathering, silty and micaceous with dark carbonaceous wisps. Soft and clayey. (Dip 1 in 4½)	2	5	22	11
Sandstone, whitish grey, fine-grained harder with dark carbonaceous wisps at intervals. Jointed in lower part ..	1	7	24	6
Sandstone and mudstone, crushed and squeezed	1	8	26	2
Mudstone, dark grey, slickensided, crushed and squeezed, soft and clayey	2	4	28	6
Mudstone, black, hard, rather splintery, carbonaceous, finely micaceous (*broken core*)	0	6	29	0
Thick (*workings*). **Coal** (*broken core*), limonitic staining on joints	9	10	38	2
Mudstone, brown, silty, iron-rich pyritic (probably hard stone parting)	0	1½	38	3½
Mudstone, black, carbonaceous, finely silty and micaceous, (*broken core*)	0	8½	39	0
Clay, pale grey, soft, waterlogged probably originally grey mudstone	2	2	41	2
Mudstone, brown, iron-rich, hard silty with many roots ..	0	5	41	7
Coal, hard, bright with inferior bands (*broken core*) ..	1	5	43	0
Clay, pale grey, soft with unweathered mudstone fragments	1	0	44	0
Clay, pale grey with carbonaceous shale and coal particles and small pink ash or brick fragments (*old workings*) ..	0	8	44	8
Heathen. Coal (*broken core, old workings*)	3	1	47	9
Clay, black	0	3	48	0
Seatearth, dark brownish grey, highly slickensided, brown ironstone nodules	2	0	50	0
Mudstone, grey, fairly soft and smooth (Dip 1 in 3 to 1 in 3½). Brown ironstone band 1 in thick at 52 ft. Occasional faint trails	4	4	54	4
Mudstone, dark grey, crushed and slickensided	0	3	54	7
Ironstone, hard, brown	0	2½	54	9½
Mudstone, dark brownish grey, soft rather clayey, badly slickensided and crushed (under above ironstone band), brown iron-rich patches	3	8½	58	6
Mudstone, grey, badly slickensided and crushed ..	1	1	59	7
Ironstone, pale brownish grey, hard splintery (Dip 1 in 2½ to 1 in 3)	0	2	59	9
Mudstone, grey, badly slickensided, crushed, fairly smooth	1	7	61	4
Ironstone	0	2	61	6
Mudstone, grey, slickensided	0	2	61	8
Ironstone, brownish grey	0	2	61	10
Mudstone, grey, soft, slickensided	1	0	62	10
Ironstone, brown, pale, hard	0	2	63	0
Mudstone, grey, fairly smooth with slickensided bands ..	0	10	63	10
Ironstone, hard, brown	0	2	64	0
Mudstone, grey, slickensided, badly crushed	0	6	64	6
Mudstone, grey, harder than above, occasional slickensides, faint trails, ironstone nodule about 65 ft	1	2	65	8

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Mudstone, black, soft clayey crushed (*small fault?*) ..	0	4	66	0
Ironstone, brown, hard	0	1	66	1
Mudstone, dark grey, fairly smooth, pyritized patches, slickensided, soft and clayey	2	2	68	3
Mudstone, dark grey, fairly smooth with pyritized patches, slickensided along bedding planes, rather shaly and harder than above, small mussels below 69 ft 9 in. Ironstone nodule at 69 ft 6 in to 69 ft 8 in with shells. Ironstone at 70 ft 8 in with shells	2	7	70	10
Stinking Marine Band. Mudstone, dark grey fairly smooth badly crushed and slickensided, similar to above with pyritized patches and trails. *Lingula sp.* at 70 ft 11 in ..	0	3	71	1
Ironstone, brownish grey with white ankerite on joints ..	0	1	71	2
Mudstone, dark grey, soft, slickensided; pyritized trails and patches, sporadic *Lingula sp.*	4	0	75	2
Mudstone, black, highly carbonaceous with pyrite ..	0	1	75	3

LOWER COAL MEASURES

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Stinking. Coal (*core*) apparently good quality	2	10	78	1
Seatearth, dark grey and brown mottled, fairly soft and clayey	0	11	79	0
Ironstone fragments (*probably cavings*)	0	1	79	1
Mudstone, dark grey, highly carbonaceous slickensided seatearth type	1	5	80	6
Coal (*core*) apparently inferior. (Dip 1 in 2½)	3	0	83	6
Mudstone, dark grey to black slickensided seatearth type	0	6	84	0
Clay with mudstone and ironstone fragments (*probably fault zone*)	3	0	87	0
Mudstone, black, carbonaceous with abundant plant debris; roots	0	3	87	3
Seatearth, brown, slickensided, becoming silty hard and iron-rich below 86 ft with many roots and sphaerosiderites	1	9	89	0
Clay, greyish brown (*probably cavings*)	1	0	90	0
Mudstone, dark grey, slickensided seatearth type ..	2	0	92	0
Seatearth, brownish grey, rather blocky with roots, sphaerosiderite, hard and iron-rich below 93 ft ..	2	4	94	4
Mudstone, brownish grey, sideritic with scattered roots ..	2	3	96	7
Ironstone, brown with white cleat-filled fractures.. ..	0	5	97	0
Mudstone, brownish grey, finely silty and micaceous, sideritic with scattered roots	2	9	99	9
Mudstone, brownish grey, fairly smooth sideritic, abundant plant remains	1	3	101	0
Mudstone, brownish grey, slickensided, finely micaceous, many plants, scattered roots	0	9	101	9
Mudstone, black carbonaceous highly crushed, slickensided coaly streaks	1	0	102	9
Mealy Grey? Coal (*broken core—good recovery*) rather inferior	1	3	104	0
Seatearth, dark grey, soft slickensided	0	3	104	3
Coal (*broken core—good recovery*) inferior	1	7	105	10
Seatearth, dark brownish grey, highly slickensided ..	0	6	106	4

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Dolerite, pale buff brown with whitish patches and abundant small pyrite crystals	1	3	107	7
Mudstone, black, carbonaceous with roots	0	2	107	9
Seatearth, dark grey, soft, highly carbonaceous, slickensided	0	3	108	0
Seatearth, brownish grey, slickensided with roots ..	2	0	110	0
Mudstone, dark brownish grey, smooth, shaly with many plant fragments	0	10	110	10
Seatearth, brown with dark grey patches, badly slickensided	0	9	111	7
Sandstone, brownish grey, current-bedded with dark grey silty mudstone bands, scattered roots in upper part ..	2	5	114	0
Sandstone, fine-grained becoming coarser with depth. Rather gritty between 116 ft and 119 ft 6 in. Broken and jointed throughout. Sharp erosive base	7	10	121	10
Mudstone, black, highly carbonaceous with coaly streaks	0	2	122	0
Mudstone, brownish grey, sideritic with roots. Slickensided; becoming soft and clayey below 123 ft, dark carbonaceous bands at intervals	5	3	127	9
Seatearth, brownish grey, blocky, slightly silty and micaceous, roots	2	3	130	0
Mudstone, seatearth type, dark brown and grey with red mottles; soft, slickensided and clayey	1	2	131	2
Mudstone, grey, sandy, micaceous, blocky with many roots	0	8	131	10
Sandstone, grey, medium-grained, scattered carbonaceous fragments. Current-bedded with fine-grained shaly bands rich in plant fragments; coarse gritty bands below 136 ft 3 in, very coarse below 137 ft 3 in with scattered green mudstone fragments	6	7	138	5
SILURIAN (LOWER LUDLOW SHALE)				
Mudstone, pale green, finely silty, slickensided with purple patches	0	8	139	1
Mudstone, pale greenish grey, silty, hard, and calcareous..	0	11	140	0
Total depth ..			140	0

Kate's Hill No. 3 Borehole (1965)

Surface Level +719 ft. National Grid ref. SO 9528 9005

Examined by E. G. Poole. Diamond bit cores from 20 to 146 ft.

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
SUPERFICIAL DEPOSITS				
Not seen (no cores or samples)	20	0	20	0
LOWER COAL MEASURES				
Sandstone, brown weathered, limonitized, fairly fine-grained with current-bedded dark carbonaceous wisps and partings. Grey unweathered areas in lower part ..	6	6	26	6

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Mudstone, grey, rather shaly with thin sandy wisps. Current-bedded. Soft with brown limonite weathering along joint planes. Dark carbonaceous plant fragments	2	3	28	9
Ironstone, brown, hard, splintery with abundant plant fragments	0	3	29	0
Mudstone, grey, silty, blocky, finely micaceous. (Dip 25° at 31 ft 6 in.) Two thin ironstone bands	4	0	33	0
Mudstone, darker grey with thin fine-grained sandstone wisps and dark carbonaceous plant-rich wisps	2	0	35	0
Mudstone, grey, finely silty, soft, clayey with slickensided joint-planes. Badly crushed and slickensided in lowermost 12 in	3	0	38	0
Bottom. Coal (*broken core—probably 100 per cent recovery*), mainly hard, bright and of good quality ..	4	0	42	0
Seatearth, black, soft, clayey, slickensided	0	2	42	2
Coaly shale	0	1	42	3
Seatearth, black, soft, clayey, slickensided	0	10	43	1
Mudstone, pale grey, soft, clayey (Dip 15°)	2	8	45	9
Ironstone, greyish brown, hard	0	3	46	0
Mudstone, dark grey, soft, clayey, slickensided along bedding planes. Pyritic with fish scales and poorly preserved mussels	1	0	47	0
Mudstone, grey, soft, highly slickensided and crushed with beds almost vertical between 47 ft 3 in and 48 ft. Mussels in brown ironstone at 48 ft 9 in. (Dip about 20° at 49 ft)	7	0	54	0
Mudstone, pale grey, slickensided, seatearth-type with roots and brown ironstone nodules in lower part ..	2	0	56	0
Seatearth, brown, rooty, soft, clayey and slickensided ..	3	8	59	8
Mudstone, black, highly carbonaceous, slickensided soft and crushed	0	3	60	0
Coal, inferior	0	5	60	5
Seatearth, brown, soft, clayey with black carbonaceous patches	0	7	61	0
Carbonaceous mudstone, black shaly	0	7	61	7
Clay, grey, soft with ironstone fragments	0	6	62	1
Seatearth; mudstone, brown, fairly blocky with roots and carbonaceous patches	3	7	65	8
Clay, dark grey, soft, crushed mudstone	0	8	66	4
Mudstone, brown, hard, iron-rich rooty and sandy passing down into	1	2	67	6
Sandstone, brown, medium-grained with roots and carbonaceous patches. A few mudstone wisps below 71 ft	4	0	71	6
Mudstone, dark grey, silty, micaceous with brown iron-rich and dark carbonaceous patches. Sandy wisps. Many roots	2	4	73	10
Ironstone, brown with white ankerite-filled fractures and roots	0	9	74	7
Mudstone, dark grey and brown, iron-rich, silty, fairly hard with abundant roots	1	7	76	2
Ironstone, brown, hard	0	5	76	7
Mudstone, dark grey, highly slickensided	0	7	77	2

Description of Strata	*Thickness Ft*	*in*	*Depth Ft*	*in*
Mudstone, brownish grey, fissile with many well-preserved plants	1	10	79	0
Clay, grey and brown with crushed mudstone fragments (*? small fault or slip*)	2	2	81	2
?Mealy Grey. Coal, inferior (*good core.* Dip 7°)	1	0	82	2
Mudstone, dark, highly carbonaceous with coaly wisps ..	0	3	82	5
Coal, inferior (*good core*)	0	7	83	0
Coal, inferior with carbonaceous mudstone bands ..	0	5	83	5
Clay, dark soft, carbonaceous	0	3	83	8
Mudstone, black, carbonaceous with coaly wisps ..	0	8	84	4
Seatearth, brown, clayey, soft	1	6	85	10
Sandstone, brown and grey, fine-grained in upper part, coarser with depth with small green mudflakes in matrix	2	10	88	8
Mudstone, brownish grey, rather soft and clayey with roots in upper part. Darker below 92 ft	2	3	90	11
Carbonaceous shale, black, crushed	0	1	91	0
Mudstone, grey, soft, clayey with occasional ironstones. Crushed and slickensided. Dark carbonaceous patches below 94 ft, passing into	3	9	94	9
Seatearth, brown, soft, clayey with black roots	2	7	97	4
Coal, inferior with shale bands	0	6	97	10
Seatearth, black, clayey, highly carbonaceous	0	2	98	0
Seatearth, dark brown and black, highly carbonaceous with abundant sphaerosiderites	1	0	99	0
Mudstone, dark grey, rooty, rather blocky with black carbonaceous patches. Red mottles below 100 ft ..	2	0	101	0
Mudstone, grey and red mottled, poorly bedded, slickensided seatearth-type. Many sphaerosiderites below 105 ft 6 in. Yellowish mottles and purple mottles at 105 ft. Bright purple 107 to 108 ft	7	0	108	0
Mudstone, grey, blocky, silty, micaceous with roots and small red mottles	3	6	111	6
Mudstone, red and grey mottled, blocky, poorly bedded with roots and small slickensides, fairly hard and silty ..	3	8	115	2
Sandstone, pale grey, medium to coarse-grained, micaceous, massive in places with dark muddy bands. Small green mudstone flakes in lower half; very soft with small pink pebbles in lower 3 in	5	2	120	4
SILURIAN (LOWER LUDLOW SHALE)				
Mudstone, red, blocky, silty, micaceous with green mottles	0	6	120	10
Mudstone, bright greenish grey, finely silty, slickensided in uppermost 6 in. (Dip 30°)	3	10	124	8
Limestone, pale brownish grey, fine-grained, silty ..	0	4	125	0
Mudstone, greenish grey, silty, micaceous, heavy, blocky with scattered brachiopods below 125 ft	1	9	126	9
Clay, pale green, soft	0	6	127	3
Mudstone, deep greenish grey, silty, micaceous with small limestone nodules and scattered brachiopods throughout. Hard, heavy in hand specimen and calcareous. Trilobite at 144 ft	18	9	146	0
Total depth ..			146	0

Kate's Hill No. 4 Borehole (1965)

Surface Level unknown. National Grid ref. SO 9510 8977

Examined by E. G. Poole. Diamond bit cores from 15 to 135 ft.

Description of Strata	*Thickness* *Ft*	*in*	*Depth* *Ft*	*in*
SUPERFICIAL DEPOSITS				
Made ground (*no cores or samples*)	15	0	15	0
MIDDLE COAL MEASURES				
Mudstone, bluish grey, weathering to yellowish brown, soft and clayey in upper part, fairly smooth, finely silty and micaceous, occasional thin brown ironstone nodules. (Dip 17° at 17 ft)	4	1	19	1
Mudstone, dark grey, fairly smooth with many carbonaceous plant stems and small brown ironstone nodules. Brown limonitic weathering	2	5	21	6
Sandstone, yellowish brown weathering, fine to medium-grained, well-jointed and broken with dark brown goethite along joint planes. Gently current-bedded with occasional dark carbonaceous wisps	14	0	35	6
Mudstone, dark grey, silty, micaceous with carbonaceous plant stems and leaves. Thin fine-grained sandstone patches in the lower part	1	0	36	6
Sandstone, yellowish brown weathered, fine to medium-grained, well jointed with dark brown goethite and box-ironstone developed along joint planes. Dark carbonaceous wisps at intervals. (*Broken core—good recovery between 42 and 48 ft.*) Many carbonaceous wisps below 49 ft	20	9	57	3
Mudstone, grey, silty, micaceous with thin fine-grained sandstone alternations, gently current-bedded with black carbonaceous wisps. Slump-bedded at 58 ft 6 in to 59 ft	11	9	69	0
Mudstone, dark grey, finely silty and micaceous with scattered carbonaceous plant fragments and a brown ironstone nodule at 70 ft. Thin sandy wisps	1	6	70	6
Sandstone, pale grey, fine-grained with dark grey shaly and carbonaceous mudstone wisps and bands. Gently current-bedded	1	0	71	6
Sandstone, grey, fine to medium-grained, fairly massive with occasional black carbonaceous wisps. Traversed by many joint planes hading 65°–70°	3	10	75	4
Mudstone, grey, silty, micaceous, blocky with occasional thin pale grey sandstone wisps and patches. Carbonaceous plant stems and fragments, ironstones, slickensided and squeezed (*collapsed roof measures*) ..	5	8	81	0
Mudstone, darker grey, fairly smooth, blocky, slickensided and squeezed with occasional brown ironstones and scattered plant stems and fragments	4	3	85	3
Mudstone, black, finely micaceous fairly smooth, slickensided and squeezed	1	9	87	0
Thick (*workings*), **Coal,** (*core, partly broken*), mainly hard bright	10	0	97	0
Coal, dust and fragments	17	0	114	0

Description of Strata	Thickness Ft	in	Depth Ft	in
Mudstone, black, shaly, fairly smooth, micaceous, carbonaceous with scattered well-preserved mussels and pyritized plant fragments	3	0	117	0
Seatearth, dark grey to black, soft, clayey, carbonaceous, bedded with plants and roots. Small ironstone nodules	4	0	121	0
Mudstone, pale grey, silty with roots and iron-rich patches	2	0	123	0
Mudstone, grey, blocky, silty, micaceous with thin pale grey sandstone wisps and patches. Scattered roots ..	3	0	126	0
Mudstone, grey, blocky, silty, micaceous with thin fine-grained, pale grey, sandstone wisps and bands. Carbonaceous plant fragment. Some sandstones show small-scale slump-structures	9	0	135	0
Total depth ..			135	0

Kate's Hill No. 5 Borehole (1965)

Surface Level unknown. National Grid ref. SO 9537 9003

Examined by E. G. Poole. Diamond bit cores from 15 to 140 ft.

Description of Strata	Thickness Ft	in	Depth Ft	in
SUPERFICIAL DEPOSITS				
Made ground (*no cores or samples*)	15	0	15	0
Made ground, clay, dark grey, soft with brick pebbles, ironstone fragments	1	0	16	0
Mudstone grey, blocky, weathering yellowish brown, occasional small ironstone nodules	2	0	18	0
Sandstone, brownish grey, fine-grained, current-bedded well cemented, iron-rich with occasional slickensided mudstone bands	4	0	22	0
Mudstone, grey, silty, micaceous, scattered plant fragments, sandy patches	0	11	22	11
Mudstone, grey, rather soft, finely silty, small brown ironstone nodules at intervals and iron-rich patches, blocky. Slightly slickensided below 29 ft	8	1	31	0
Mudstone, grey, soft, clayey, crushed and slickensided with increasing dip. (Dip 1 in 3)	1	0	32	0
Mudstone, grey blocky, slightly silty, slickensided bedding planes at intervals, few plant fragments, occasional thin brown ironstone nodules, limonitic staining along joints and especially along jointed ironstones between 35 and 39 ft. (Dip increasing to 1 in 1½)	11	6	43	6
Mudstone, dark grey, soft, clayey, badly slickensided and crushed with many plant fragments, some coaly. (Dip 1 in 1½)	0	6	44	0
Mudstone, grey, blocky, finely silty and micaceous with scattered plants. (Dip 1 in 3½). Limonitic staining along joints in lower parts	4	0	48	0
Ironstone, brown, limonitic	0	2	48	2

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
Sandstone, yellowish brown with abundant limonitic staining, fine-grained, micaceous. Occasional current-bedded, carbonaceous, black wisps. Well-jointed, abundant highly carbonaceous shaly wisps and coaly plants between 69 ft 6 in and 70 ft 6 in, medium-grained below 71 ft 7 in. Coal inferior and probably drifted 7 in thick at 75 ft 6 in. Becoming fine-grained below 75 ft 6 in	29	6	77	8
Ironstone, brown, silty	0	2	77	10
Mudstone, grey, silty, micaceous with thin fine-grained sandstone wisps with scattered carbonaceous plant fragments	3	2	81	0
Ironstone, pale brown, hard, splintery	0	4	81	4
Mudstone, grey, blocky, silty with thin, pale grey, fine-grained sandstone wisps at intervals, becoming more abundant with depth. Ironstone band at 84 ft 10 in to 84 ft 11 in	4	0	85	4
Sandstone, pale grey, fine-grained with scattered black carbonaceous current-bedded wisps	7	6	92	10
Ironstone, brownish grey, limonitic staining along joints ..	0	3	93	1
Mudstone, grey, silty, micaceous, becoming finer grained with depth with slickensiding along bedding planes; a few lenticular ironstone nodules and scattered plant fragments, brown ironstone band at 98 ft 8 in to 98 ft 10 in	6	11	100	0
Mudstone, grey, finely micaceous, fairly smooth with thin brown ironstone bands at intervals, soft, slickensided along bedding planes, scattered slickensided mussels below 103 ft	4	8	104	8
Mudstone, dark grey, slickensided, rather carbonaceous ..	0	6	105	2
Shale, black, finely micaceous with scattered fish scales and mussels in lower part	3	0	108	2
Mudstone, black, highly carbonaceous—almost an inferior coal. (Dip 1 in 2 to 1 in 2½)	0	10	109	0
Thick. Coal (*core*) inferior (*fragments from 114 to 119 ft*) clay band at 119 ft 6 in to 119 ft 8 in	27	5	136	5
Mudstone, black, carbonaceous, finely silty, hard in upper part becoming soft and slickensided with depth, abundant roots	2	1	138	6
Mudstone, grey, soft, clayey, slickensided, rooty	0	6	139	0
Mudstone, paler than above, soft, slickensided with roots	0	9	139	9
Ironstone, dark brownish grey with white ankerite along joints	0	3	140	0
Total depth	..		140	0

Penn (Baggeridge) No. 1 Borehole (1954–55)

Surface Level about +440 ft. National Grid ref. SO 8933 9706

Examined by R. H. Hoare. Percussive drilling from surface to 459 ft, rotary roller-bit from 459 ft to 1892 ft 4 in, diamond bit cores from 1892 ft 4 in to 2491 ft 7 in.

Description of Strata	*Thickness* *Ft*	*in*	*Depth* *Ft*	*in*
SUPERFICIAL DEPOSITS, PERMO-TRIASSIC and UPPER COAL MEASURES (*Badly contaminated samples*)	1892	4	1892	4
HALESOWEN BEDS				
Mudstone, pale grey with roots and ironstone bands ..	8	5	1900	9
Seatearth, pale grey	3	0	1903	9
Mudstone, grey, silty	0	9	1904	6
Sandstone, grey with silty mudstone bands	8	6	1913	0
Mudstone, grey, silty, finer-grained with depth	2	9	1915	9
Mudstone, grey, with plant and ironstones	1	9	1917	6
Coal (*fragmentary core*)	0	0½	1917	6½
Seatearth, greenish grey, becoming silty	3	0½	1920	7
Seatearth, black, carbonaceous	0	2	1920	9
Coal, pyritous	0	6	1921	3
Seatearth, pale grey, soft, friable becoming silty	7	3	1928	6
Mudstone, pale greenish grey, rooty and silty	6	0	1934	6
Sandstone, pale grey with silty mudstone bands	2	3	1936	9
Mudstone, grey, silty with sandy wisps	5	3	1942	0
Sandstone, pale grey, fine-grained	3	9	1945	9
Mudstone, grey, with roots and dark grey carbonaceous bands in lower part	2	3	1948	0
Mudstone, dark grey, shaly, carbonaceous	0	7	1948	7
Seatearth, grey; greenish grey and silty below 1949 ft ..	2	5	1951	0
Sandstone, pale greenish grey, fine-grained becoming coarse and gritty with many mudstone pellets in lowest 9 in	49	2	2000	2
Sandstone, grey, fine-grained with silty wisps	1	10	2002	0
Mudstone, pale greenish grey, slightly silty with limestone band from 2005 ft 5 in to 2006 ft 2 in, reddish brown tinged in places	27	7	2029	7
Coal (*broken core*)	5	6	2035	1
Mudstone, greyish brown, rooty, becoming silty	7	11	2043	0
Sandstone, grey, massive, pebbly	2	6	2045	6
Mudstone, grey, brown, variegated with yellowish purple, lilac in places, sandy below 2069 ft	26	6	2072	0
Sandstone, greenish grey, medium to coarse with mudstone pellets	2	9	2074	9
Mudstone, greyish brown silty with chocolate and reddish brown mottles	10	6	2085	3
Mudstone, pale grey variegated in places with bands of pale grey sandstone	7	0	2092	3
Mudstone, pale greenish grey becoming variegated with depth	2	6	2094	9
Seatearth, black, shaly, carbonaceous	0	9	2095	6
Seatearth, dark grey, reddish brown and purple mottled passing into variegated silty mudstone	10	0	2105	6
Sandstone, pale to cream coarse-grained with small pebbles	6	7	2112	1

Description of Strata	Thickness Ft	Thickness in	Depth Ft	Depth in
MIDDLE COAL MEASURES				
Mudstone, pale grey with greenish mottles, slightly silty in upper part, darker grey with depth	13	7	2125	8
Shale, black, carbonaceous with sandy veins	1	5	2127	1
Brooch. Coal with mudstone bands	1	6	2128	7
Seatearth, dark grey, silty	1	5	2130	0
Mudstone, dark grey, with a few mussels	2	0	2132	0
Sub-Brooch Marine Band. Mudstone, dark grey, with *Lingula sp.*	0	10	2132	10
Sandstone, pale grey with carbonaceous wisps	13	2	2146	0
Mudstone, grey, silty with ironstone bands; less silty with depth	10	10	2156	10
Mudstone, dark grey to black; fish remains	0	9	2157	7
Coal (*broken core*)	1	4	2158	11
Coal and shale	1	1	2160	0
Seatearth, grey, silty passing into silty mudstone with plants	8	9	2168	9
Shale, black, with fish remains	0	1	2168	10
Seatearth, black, shaly with coal streaks	1	2	2170	0
Seatearth, grey, silty passing into silty mudstone with thin ironstone bands	8	6	2178	6
Mudstone, grey with thin ironstone bands	4	9	2183	3
Coal (*core and fragments*)	0	8	2183	11
Seatearth, black, shaly, carbonaceous	0	5	2184	4
Seatearth, grey, becoming silty with depth, passing into silty mudstone with sandy patches and plants	15	8	2200	0
Mudstone, grey, silty with wisps and bands of fine-grained sandstone; carbonaceous wisps	26	0	2226	0
Sandstone, pale grey with carbonaceous wisps, fine-grained	10	6	2236	6
Mudstone, grey, slightly silty	0	9	2237	3
Thick. Coal	7	3	2244	6
Seatearth, dark carbonaceous	3	8	2248	2
Coal	9	7	2257	9
Seatearth, dark, carbonaceous and soft grey friable	4	3	2262	0
Shale, black, plant-rich	1	0	2263	0
Shale, black, canneloid, with fish remains	1	6	2264	6
Mudstone, grey with sporadic mussels and fish remains	1	0	2265	6
Mudstone, grey, silty, with plants and ironstones	5	6	2271	0
Mudstone, grey, silty, with mussels	3	2	2274	2
Heathen. Coal	1	5	2275	7
Seatearth, grey and brown, becoming silty with ironstones	4	9	2280	4
Mudstone, grey, silty with sandy wisps	3	2	2283	6
Rubble (Lower Heathen). Coal	1	5	2284	11
Seatearth, pale grey, silty	2	6	2287	5
Sandstone, pale grey with silty wisps	2	6	2289	11
Mudstone, grey, silty with sandy wisps and thin ironstone bands	14	1	2304	0
Mudstone, grey, slickensided	2	0	2306	0
Ironstone, grey	1	0	2307	0
Mudstone, grey with thin ironstone bands; mussels in lower part	2	9	2309	9
Stinking Marine Band. Mudstone, grey, pyritous, with *Lingula sp.*	0	9	2310	6

Description of Strata	*Thickness* *Ft*	*in*	*Depth* *Ft*	*in*
Stinking. Coal	1	0	2311	6
Seatearth, grey, becoming silty	6	6	2318	0
Mudstone, grey, silty with roots	2	0	2320	0
Mudstone, grey, silty with sandstone bands and patches . .	20	9	2340	9
New. Coal	2	10	2343	7
Seatearth, greyish brown; carbonaceous bands	4	10	2348	5
Fireclay. Coal with dirt bands	3	4	2351	9
Mudstone, black carbonaceous	0	6	2352	3
Seatearth, greyish brown, silty with carbonaceous bands . .	7	10	2360	1
Shale, black, coaly	0	6	2360	7
Coal	0	6	2361	1
Seatearth, black, shaly	0	8	2361	9
Seatearth, grey and brown with carbonaceous mudstone bands and ironstones	11	10	2373	7
Shale, black	0	2	2373	9
Mudstone, grey, slightly silty	1	0	2374	9
Shale, black, with fish remains	0	1	2374	10
Coal, shaly	0	2	2375	0
Seatearth, dark grey passing into grey sandy mudstone . .	9	6	2384	6
Sandstone, pale grey, medium-grained	2	8	2387	2
Seatearth, grey, silty	1	5	2388	7
Bottom. Coal with dirt bands	6	7	2395	2
Seatearth, black, carbonaceous	0	1	2395	3
Sandstone, pale grey, fine-grained, coarser with depth . .	6	3	2401	6
Mudstone, grey, slightly silty, rooty	4	0	2405	6
Seatearth, grey with roots and ironstones	4	0	2409	6
Coal	0	3	2409	9
Seatearth, grey, sandy	0	9	2410	6
Coal, shaly	0	6	2411	0
Seatearth, greyish brown with dark carbonaceous bands . .	8	7	2419	7
Coal	0	7	2420	2
Seatearth, dark grey, carbonaceous	1	6	2421	8
Coal	1	7	2423	3
Seatearth, pale grey and brown passing into silty mudstone	4	9	2428	0
Sandstone, pale grey	1	4	2429	4
Mudstone, grey, silty with sandy wisps	2	10	2432	2
Seatearth, grey and green passing into silty grey mudstone	4	4	2436	6
Sandstone, grey, fine-grained becoming coarse and conglomeratic	13	6	2450	3
Mudstone, pale grey, slightly silty	0	5	2450	8
Seatearth, carbonaceous in upper part	3	9	2454	5
Mudstone, greenish grey with thin gritty bands	5	1	2459	6
Sandstone, pale grey	2	1	2461	7
Mudstone, grey with sandstone bands; plants	0	10	2462	5
OLD RED SANDSTONE (DOWNTONIAN)				
Mudstone, green, silty with calcareous nodules	15	7	2478	0
Mudstone, red, brown, green and grey mottled with calcareous nodules	13	7	2491	7
Total depth	. .		2491	7

Porter Street No. 1 Borehole (1965)

Surface level about + 665 ft. National Grid ref. SO 9481 9019

Examined by L. S. O. Morris. Diamond bit cores from surface to 140 ft.

Description of Strata	*Thickness*		*Depth*	
	Ft	*in*	*Ft*	*in*
SUPERFICIAL DEPOSITS				
Made ground, concrete, bricks and rubble	4	0	4	0
Clay, pale grey with sandstone and coaly patches ..	11	0	15	0
LOWER COAL MEASURES				
Coal, inferior	0	6	15	6
Seatearth, dark grey, shaly, clayey	0	9	16	3
Sandstone, whitish grey, medium-grained with carbonaceous wisps	3	3	19	6
Sandstone, grey, shaly	0	6	20	0
Mudstone, dark grey, shaly	0	6	20	6
Seatearth, pale brown, sandy with roots	1	6	22	0
Sandstone, pale brownish grey, gritty	1	11	23	11
Mudstone, grey, shaly, soft	1	1	25	0
Ironstone, grey	0	6	25	6
Clay, grey, soft	6	3	31	9
Coal, inferior	0	6	32	3
Seatearth, greyish brown, clayey	3	9	36	0
Coal, inferior	0	2	36	2
Seatearth, greyish brown, clayey becoming harder and silty with depth	2	10	39	0
Mudstone, grey, shaly with sandstone alternations, coaly streaks and partings	1	6	40	6
Sandstone, pale grey, medium-grained with gritty patches. A few coaly streaks	11	0	51	6
Sandstone, greyish brown, coarse, gritty. (*Brecciated at base, small fault*)	2	1	53	7
Seatearth, grey, shaly..	0	11	54	6
Sandstone, grey with mudstone alternations	1	4	55	10
Mudstone, grey, shaly, seatearth-type	0	11	56	9
Mudstone, red and green mottled. Shaly	1	3	58	0
Sandstone, red and greyish green (*broken*)..	3	8	61	8
Grit, grey, hard and conglomeratic	0	10	62	6
Seatearth, brown and red, soft, iron-rich	2	0	64	6
Mudstone, grey, shaly (*broken core*)	0	10	65	4
Sandstone, pale grey, fine-grained	1	1	66	5
Mudstone, dark grey with coaly wisps	0	11	67	4
Grit, grey and green, coarser with depth	1	8	69	0
Mudstone, grey, silty, micaceous, soft and clayey in lower part	0	7	69	7
Grit, pale grey, with fine-grained sandstone and coarse conglomeratic bands	8	1	77	8
Mudstone, grey, soft, shaly becoming harder and silty below 79 ft	3	1	80	9
Sandstone, pale grey, fine-grained	0	10	81	7
Mudstone, grey, silty, hard, micaceous	0	7	82	2
Sandstone, pale grey, fine-grained becoming coarser downwards with carbonaceous wisps	6	0	88	2

Description of Strata	Thickness Ft	in	Depth Ft	in
SILURIAN (LOWER LUDLOW SHALE)				
Mudstone, grey, silty, slightly calcareous with brachiopods, trilobites, nautiloids and pyritized 'fucoid' markings. Soft and shaly from 98 to 101 ft; fine-grained limestone band at 106 ft 3 in to 106 ft 5 in. Becomes greenish grey, more silty and less fossiliferous below 118 ft 3 in with thin fine-grained limestone band at base	35	10	124	0
Mudstone, dark greyish green, micaceous softer, less silty than above, calcareous with pyritized 'fucoid' markings. Limestone bands from 125 ft 8 in to 126 ft and thin limestone bands at intervals below. Rare fossils ..	16	0	140	0
Total depth ..			140	0

II.—SOME ASPECTS OF THE GLACIAL GEOLOGY OF WEST INVERNESS-SHIRE

BY

J. D. PEACOCK, B.SC., PH.D.

Text-figures 1–4

Summary. From a consideration of features of ice movement it is suggested that during the last glacial episode in west Inverness-shire (correlated with the Loch Lomond Readvance) small ice caps were centred near the heads of Glen Kingie and Loch Arkaig. The principal ice-shed at this time lay a little east of the present-day watershed, and during earlier glacial episodes may have lain still farther east. The relationship of the raised beaches to the outlet glaciers of the Loch Lomond Readvance is discussed.

INTRODUCTION

THE AREA DESCRIBED in the following account comprises some 800 square miles of the Highlands between the Great Glen and the sea-board from Loch Nevis to Ardnamurchan, i.e. the ground covered by the One-inch sheets 52, 61 and 62 of the Geological Survey (Scotland). Apart from a summary of glacial retreat stages by Charlesworth (1956) and a more extended account of the Lochy-Spean area by the writer (Peacock 1970), only the fringes of this district have been treated from the point of view of the glacial geologist. The purpose of this paper is to put forward evidence obtained during mapping by the Institute of Geological Sciences.

The West Highlands was one of the major centres of ice accumulation during the Pleistocene, and at the close of the last (Weichselian) glaciation, ice probably survived there to a relatively late date. Throughout much of the area the features and deposits are those produced by the last readvance of ice (the Loch Lomond Readvance), and only in Morvern, Ardnamurchan, and the coastal strip extending to Knoydart, is there unequivocal evidence of glacial events earlier in the Weichselian (Fig. 1).

There is little evidence also in much of the West Highlands for Pleistocene erosional features predating the Weichselian glaciation. In Ardnamurchan, however, there is preserved the well-known 'pre-Glacial' rock platform at 100 to 150 ft (30–45 m) O.D. (Bailey and others 1924; Wright 1937) which was almost certainly formed prior to the last glaciation, and in Rhum a well-preserved raised beach platform at about this level is strongly glaciated on the side of the island facing the mainland (McCann and Richards 1969; Peacock 1969). The erosion of part of the '25-ft' (8 m) beach platform and cliff in the Firth of Lorne and the Sound of Mull may also have taken place before glaciation (McCallien 1937; McCann 1966a; Synge and Stephens 1966).

As the ice withdrew from its maximum position, isostatic readjustment of the land together with eustatic changes in sea-level gave rise to a complex series of raised beaches. The earlier (late-Glacial) beaches reach a height of at least 135 ft (41 m) O.D. in the Morar area, and, as elsewhere in Scotland, are presumed to be separated in time by a period of low sea-level from the post-Glacial beaches, which reach a maximum height of just over 40 ft (12 m) O.D. along Loch Eil side (Jamieson 1865; McCann 1966a; Sissons 1966). McCann (1966b) and Sissons (1966) support the view that the last glacial episode, correlated with the Loch Lomond Readvance (Simpson 1933), took place when the late-Glacial sea-level was near or below that of the post-Glacial maximum.

FEATURES OF ICE MOVEMENT

The features of ice movement can be considered roughly in terms of the glacial history, i.e. those formed during an early phase, when ice probably covered the whole land surface, and those produced at a time when the ice had withdrawn from much of the coast.

Features of the earlier glacial phase. A record of the movement of ice during this phase of maximum glaciation is preserved in erosional forms (striae, roches moutonnées, and glacial grooving) of the coastal areas and high ground in the west. It is also seen in the dispersal of erratics of the Strontian Granite (Fig. 1); and of various Moinian rocks (*Summ. Prog.* for 1936). Elsewhere the evidence has been obliterated by later glacial activity. Ice flowing south-west along Loch Linnhe was deflected north-west across Morvern and Ardnamurchan by the dispersal of ice from the Mull centre (Bailey and others 1924) and from the ground east of Loch Linnhe; farther north the movement was probably to the west or north-west. Though direct evidence is lacking, an inspection of the trend lines of ice movement shown in Fig. 1 suggests that the ice-shed during this phase lay well to the north-east of Loch Eil, and east of that deduced for the Loch Lomond Readvance. Similar displacements of the ice-shed have been reported for the highland areas south of the Great Glen (Hinxman and others 1923) and for districts farther north (Peach and others 1913).

Features of the later glacial phase. Features of ice movement which were produced during the later glacial phase are shown in Fig. 2. These suggest firstly that the ice-shed lay east of the principal watershed, at least in the northern two-thirds of the area shown in the diagram, and secondly that local ice caps were centred about the heads of Loch Arkaig and of Glen Kingie.

Striations, grooves, and moutonnéed surfaces are well preserved in districts west of the granite gneiss outcrop. The striations on pelitic rocks are large and deep (5–10 mm) compared with the fine scratches on the psammites. At an early stage of weathering the latter type of striations disappear, and can commonly be found only where till is stripped away. Thus the cluster of observations west of the granite gneiss can be explained partly by the preservation of the deeper type of striation in the pelitic and semipelitic rocks which are found especially in the Glenfinnan Division and the Morar Division metamorphic rocks, which lie to the west of the gneiss (Johnstone and others 1969), in contrast to the dominant psammites in the Loch Eil Division to the east. In the Loch Quoich area the distribution of striae suggests that an ice-shed lay from north to south across the middle of the loch, about 3 miles (5 km) E. of the present-day watershed, and in Glen Kingie ice certainly flowed westwards across the high col (2700 ft, 823 m) at the head of the valley.

Morainic features oriented in the direction of ice movement occur in Glen Garry and the lower Kingie valley (Peacock 1967) where they give a particularly clear indication of ice movement (Fig. 2). They may be compared with the 'fluted drift' which occurs elsewhere in the Highlands (Sissons 1967), which, to judge from published observations to date, is largely associated with the Loch Lomond Readvance.

Erratics derived from the granite gneiss, the 'injected' pelitic belt of the Glenfinnan Division west of the gneiss, the highly distinctive Glen Dessary syenite, and the dolerite of the Meall a'Phubuill vent, are of interest in assisting the determination of directions of ice flow. In the Loch Arkaig area erratics of granite gneiss and 'injected' pelite derived from the head of the loch are dispersed eastwards, together with a few boulders of Glen Dessary syenite (one of these being found as far east as Spean Bridge in the Great Glen). Boulders of syenite also occur plentifully west of the outcrop. From this evidence the ice-shed was probably situated over the Glen Dessary syenite, nearly 8 miles (13 km) E. of the present-day principal watershed. Farther south the south-south-

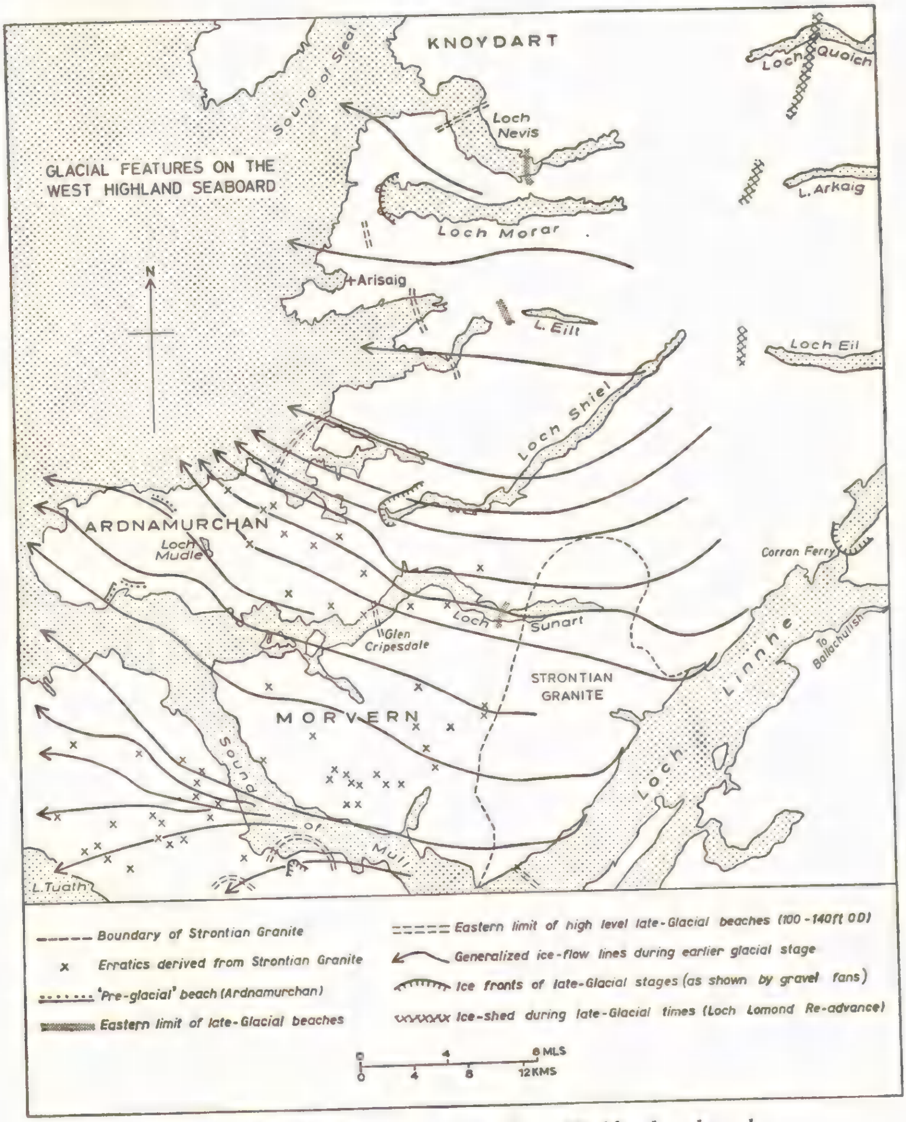

FIG. 1. *Glacial features on the West Highland seaboard*

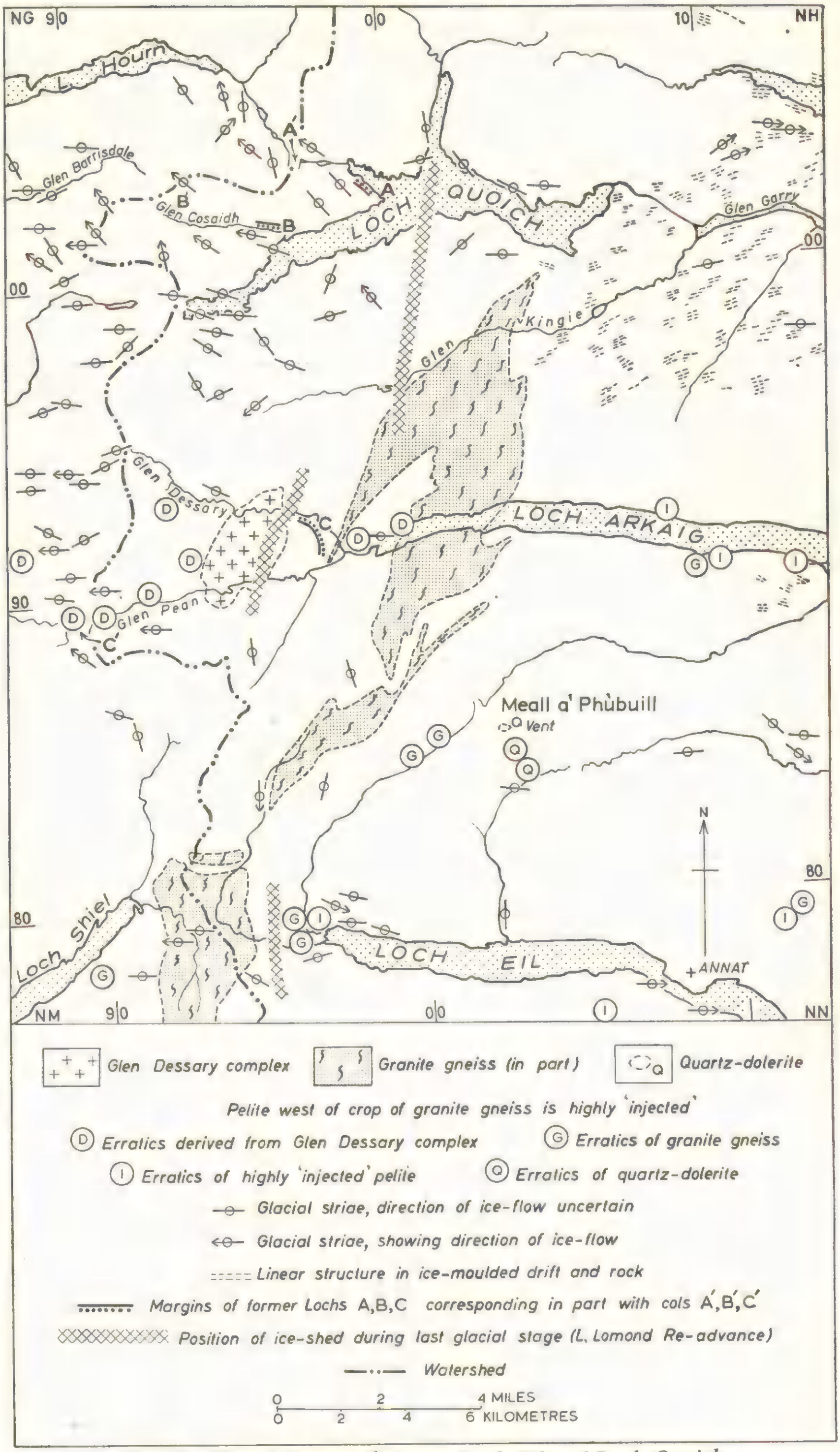

FIG. 2. *Glacial features between Loch Eil and Loch Quoich*

eastward carry of erratics of the Meall a'Phubuill dolerite (which crops out west of the summit of the hill [NN 030 853]) matched by the scattered observations of striation directions, implies a southward flow of ice towards Loch Eil.

In the Loch Eil valley the evidence of ice movement is less clear than farther north. The westward flow of ice across the col towards the head of Loch Shiel was noted by Dury (1953) and confirmed by Geological Survey observations, but the direction of flow at the head of Loch Eil itself is uncertain. Erratics of granite gneiss and 'injected' pelite are very sparsely distributed along Loch Eil side and it is probable that those recorded in Fig. 2 were derived from the north, rather than from outcrops at the head of the loch. In the Great Glen the Loch Eil ice split, one arm flowing north-eastwards (Peacock 1970) and the other south-westwards, as attested by large curving shallow grooves high up on Meall an t-Slamain opposite Fort William. The westward-flowing ice from Loch Eil also split, one branch following the Loch Shiel valley, and the other moving towards Loch Eilt, across the fine glaciated rock barrier seen by the roadside [NM 857 813].

The picture of ice movement in the district east of that shown in Fig. 2 has been described in detail elsewhere (Peacock 1970). Here the recent evidence supports an earlier suggestion (Grant Wilson *in Summ. Prog.* for 1899) that ice crossed the Great Glen to contribute towards the ice barrier which dammed the 'Parallel Road' lakes of Glen Roy. The eastward limit of the Loch Lomond Readvance ice may have been in Glen Gloy and Glen Roy (Peacock 1970; Sissons 1967).

Till

In the West Highlands the till takes the form of boulder clay and morainic drift, these deposits differing mainly in the nature of the matrix and in their degree of cohesion.

Boulder Clay. Stiff grey till with a clayey matrix is of sporadic occurrence but is found at a number of localities, for instance on the south side of Loch Eil where up to 10 ft (3 m) may be seen below morainic drift in stream-side exposures. The contact with the morainic drift is commonly sharp, but gradations from one material into the other have been noted. Similar material occurs below morainic drift in stream sections north of the River Lochy. The boulder clay in these areas, which are well within the limits of the Loch Lomond Readvance, could be lodgement till of the last glacial phase or, less likely, the remains of an earlier drift sheet.

Thin stony drift with striated pebbles has been mapped as boulder clay on the Tobermory (52) Sheet near Loch Mudle, Ardnamurchan [NM 543 662].

Morainic Drift. Much of the glacial drift in the West Highlands has been mapped as 'morainic drift' by the Geological Survey. This is generally a poorly sorted deposit, consisting of subangular to rounded pebbles, cobbles, and boulders in a silty, sandy groundmass. At some localities there is a crude bedding structure. The drift in places passes into, or includes, masses of sand and gravel. Striated rock fragments are much less common in morainic drift than in the boulder clay.

The form assumed by the morainic drift is variable. At many localities the topography is a chaos of low mounds, some of which conceal rock knobs; elsewhere, particularly on the sides of some valleys, the drift forms smooth sheets which grade upslope into hillwash. More regular morainic forms occur in the Glen Spean area (p. 51), where they have been likened to terminal moraines (Livingstone 1906; Lawrie *in Summ. Prog.* for 1952), and to disintegration ridges and cross-valley moraines (Peacock 1970). In some districts, for instance on the south side of Loch Eil, at the east end of Loch Arkaig, and particularly in the Loch Garry area low hummocks of morainic drift are oriented parallel to the direction of ice movement (p. 44). It is thus probable that the morainic drift includes both ground moraine and ablation till.

The distribution of glacial drift shows anomalies. East of the ice-shed between one-half and two-thirds of the terrain is drift covered, but west of it the drift is sparse or absent. The western limit of morainic drift coincides roughly with the eastern limit in the sea-lochs of the highest late-Glacial beaches (Wright 1937, p. 373). Charlesworth (1956, pp. 895–7) in discussing the lack of drift in the west (the 'Moraineless West') suggests that it might have been a consequence of the rapid disappearance of the ice in this area. This explanation is unconvincing because the ice has clearly eroded and removed vast amounts of debris, and the wasting of such ice would result in the deposition of drift. It follows that the last ice to occupy this area was clean, and less able to erode the underlying rock.

Meltwater Deposits

The main occurrence of meltwater deposits within the area covered by the three one-inch sheets referred to in this account is in the area between Spean Bridge and Fort William. These have been described by Grant Wilson (*in Summ. Prog.* for 1899) and Peacock (1970), and are interpreted as pro-glacial lake deposits, sub-glacial accumulations and fluvio-glacial deposits associated with the retreat of the Loch Lomond Readvance ice. Other notable areas underlain by meltwater deposits occur at the west end of Loch Shiel and at the west end of Loch Morar.

At the west end of Loch Shiel there are large accumulations of stratified sediments (McCann 1966b, Geological Survey One-inch Tobermory (52) Sheet, Drift Edition, 1968). These probably mark the maximum extent of the ice of the Loch Lomond Readvance in the Loch Shiel valley. A marginal fluvio-glacial terrace at 72 ft (22 m) O.D. which begins near the school [NM 673 681] at Acharacle (Fig. 3) merges northwards into a peat-covered spread of outwash gravel, and from kamiform deposits [674 685] within the margin of the former glacier the surveyors recorded the marine shells *Trophon clathratus* and *Cyprina islandica*, suggesting that the late-Glacial sea had invaded the Loch Shiel valley prior to the Loch Lomond Readvance. The peat-covered outwash gravels, 57 ft (17·4 m) O.D. at the ice-contact slope [672 684], maintain an almost level surface for 500 to 600 yd (457–549 m) to near the rock barrier which extends north-westwards from the road junction [666 685]. From this locality the surface falls gently westwards to merge imperceptibly into the post-Glacial storm beach of Kentra Bay. Though the gravels of the main outwash fan are poorly exposed, a quarry in a slightly lower (45 ft, 13·7 m O.D.) terrace north-west of Shiel Bridge

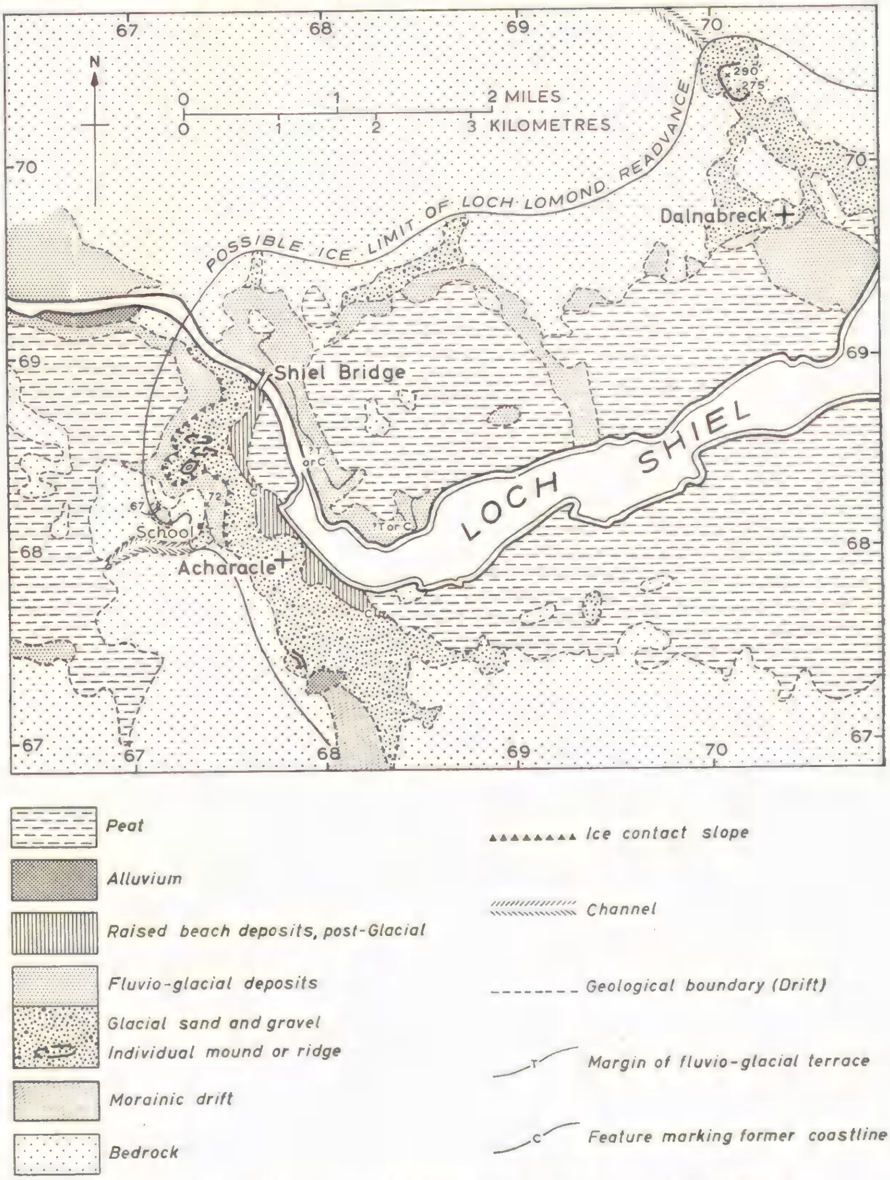

FIG. 3. *Glacial features and deposits at the west end of Loch Shiel*

[675 694] shows up to 15 ft (4·6 m) of horizontally bedded sand and gravel overlain by up to 3 ft (1 m) of sandy flow till. The sands show small sets (about 15 cm) of cross bedding.

As with other glaciers of the Loch Lomond Readvance, the margin of the Shiel glacier at its maximum extent rose rapidly away from the terminus (cf. Sissons 1967). South of Acharacle the marginal deposits reach over 200 ft (60 m) within a mile of the village, and on the opposite side of the valley, north of Dalnabreck [704 697] a prominent mound of sand and gravel reaches 290 ft

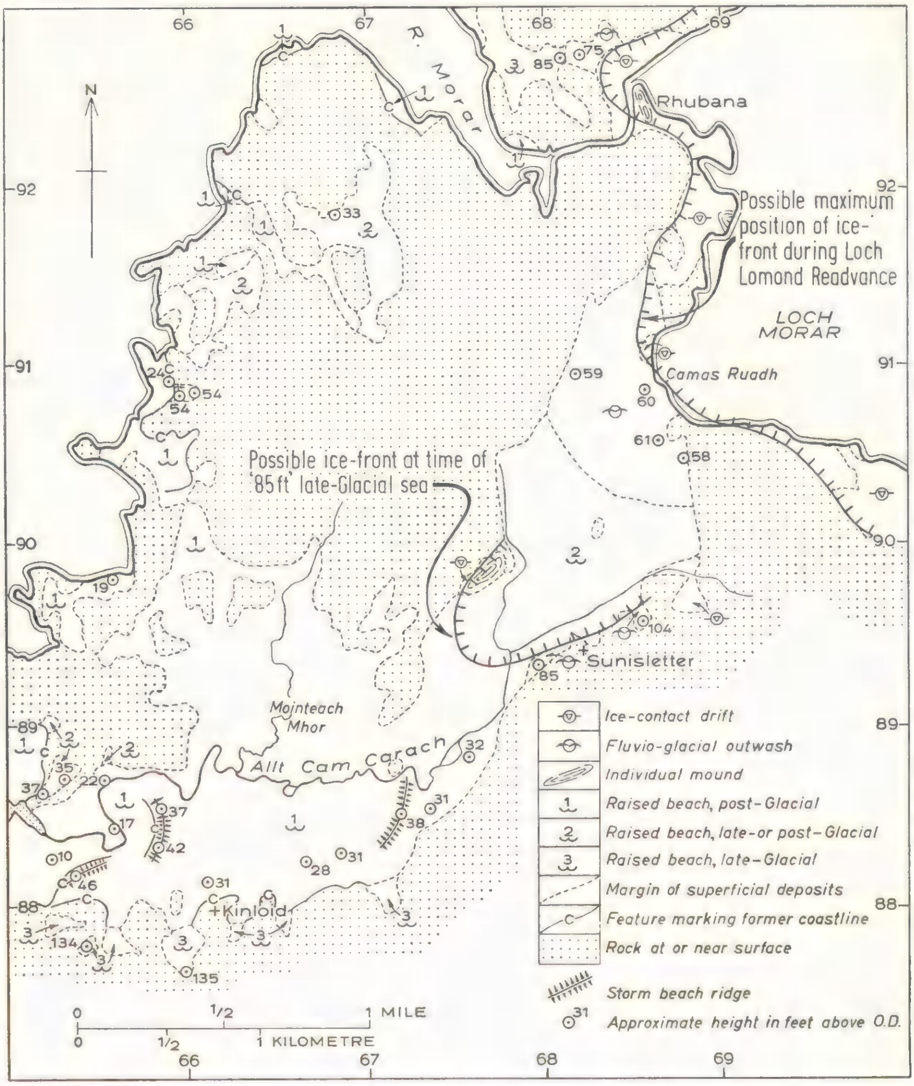

FIG. 4. *Glacial features and deposits at the west end of Loch Morar*

(88·4 m) O.D., south of a channel at about 300 ft (91·5 m) O.D. which carried meltwater north to Loch Moidart.

On the lower ground around Loch Shiel fluvio-glacial sands and gravels and glacio-lacustrine silts marking the eastward retreat of the ice can be followed for about 5 miles (8 km) to the 'narrows' about Eilean Fhianain. The outwash probably discharged into a pro-glacial lake, the surface of which was a few feet above that of the present loch.

At the west end of Loch Morar (Fig. 4) at Camas Ruadh [NM 687 907] there is an outwash fan (highest point 61 ft (18·6 m) O.D. inclusive of a thickness of peat), possibly equivalent to the Shiel outwash (McCann 1966b). East and north of the fan, kamiform deposits include gravel and reworked silts and clays of marine or lacustrine origin. At the north-west end of Loch Morar, an outwash terrace feature cuts into raised beach gravels at about 85 ft (26 m) O.D. The outwash fan at Camas Ruadh descends to about 30 ft (9 m) O.D. below the great peaty flat of the Mointeach Mhor [NM 670 890]. At Sunisletter [NM 680 893] a gravel terrace, probably deltaic, stands at 80 to 85 ft (24–26 m) O.D. Scattered boulders occur on the surface of the terrace, riven, perhaps by frost, from the crags above. The deposits here are discussed below (p. 54).

Elsewhere in the West Highland district accumulations of sand and gravel occur as eskers, and as small areas of terraced or moundy deposits marking the withdrawal of the ice across the principal watershed.

Features of Glacial Retreat

The last phases of glaciation, as the ice wasted away from the Loch Lomond Readvance maximum, were accompanied by numerous adjustments of the drainage, which expressed themselves as meltwater channels, erosional features, and as deposits of fluvio-glacial and glacio-lacustrine sand and gravel.

In the Spean valley the late-Glacial history has already been described (Peacock 1970), but the brief summary is as follows. After the draining of the '860 ft' Parallel Road lake, the water probably escaped partly sub-glacially, and partly sub-aerially, eventually finding its way into Loch Lochy and escaping north-eastward through the Great Glen. Meltwater from ice in the valley of the River Lundy discharged eastwards across a col into a glacial 'Lake Lianachain', and thence via the Cour valley into the River Spean. At a late stage meltwater from ice still present in the River Lochy valley drained into an enlarged Loch Lochy, and the south-westerly flow of the River Lochy was established only as the ice finally disappeared from the district.

Farther north within the district dealt with in this paper, the ice in the Arkaig and Quoich areas retreated eastwards across the principal watershed, its withdrawal being marked by the formation of glacial lakes which discharged either across the watershed to the west or along the ice margin.

The evidence of such retreat is well seen in the Loch Quoich basin (Fig. 2). A short stretch of terrace at (A) is at the same height (about 725 ft, 221 m O.D.) as the Quoich/Hourn watershed (A^1). Similarly, in Glen Cosaidh a terrace (B) on the north side of the valley is at much the same height as the lowest point of the pass (B^1) into Barrisdale. These terraces mark the levels of short-lived lakes held back by the ice as it retreated eastwards across the watershed. In Glen Cosaidh deposits of sand and gravel occur immediately east and south of the col (B^1), and extend down the glen for over a mile. They were probably deposited in the temporary lake by meltwaters derived from ice wasting away eastwards and perhaps into the side valleys.

At the head of Loch Arkaig a terrace (C) probably marks the shore of a lake which discharged across the col (C^1) at the west end of Glen Pean; this latter is now partly blocked by a landslide, and the Ordnance Survey spot height on or near the col (504 ft, 153 m) is much above the level of the former watershed. Scattered deposits of sand and gravel occur east of the col for some three miles

(5 km), and above Glenpean House [NM 936 902] there are lacustrine or ice-marginal terraces cut in morainic drift. It is probable that the deposits and features in Glen Pean are related to downwasting ice with an ice front retreating eastwards towards the former ice-shed.

At Annat, the pulp mill stands on a broad gravel terrace graded to the highest level of the post-Glacial Sea (about 40 ft, 12 m O.D.). In bores seaward of the pulp mill the deposits reach a thickness of nearly 200 ft (60 m) without reaching rockhead and include gravel, sand and silt. About half a mile west of the Annat Burn a low gravel mound cut by the railway rises above the level of the beach terrace. It is suggested that the Annat gravels are glacial gravels reworked by the post-Glacial sea; they may at one time have formed a local terminal moraine across the entrance to Loch Eil, analogous to the gravels at Ballachullish (McCann 1966b).

The features of ice retreat noted above provide independent confirmation of the view put forward earlier, that the ice-shed during the Loch Lomond Re-advance was some distance east of the present watershed. They are also in accord with the idea that not long after the ice began to withdraw it became stagnant, receiving little or no addition from the high corries of the mountains nearby. The details of the glacial retreat stages envisaged by Charlesworth (1956) have not been confirmed.

Raised Beaches

As mentioned above, the raised beaches fall into two groups; a late-Glacial series which coincides with the last phases of glaciation, and a post-Glacial series. Elsewhere in Scotland an intervening period of low sea-level is shown by the occurrence of peat, which overlies the late-Glacial beaches, but underlies the later series (Jamieson 1865; Sissons 1966). This peat, the Boreal peat, may be represented by the plant bed overlain by beach gravel formerly seen near Fort William (Bailey and Maufe 1960, p. 280), but at Glengalmadale (Tobermory (52) Sheet) a peaty deposit overlying green marine clay and overlain by beach or alluvial gravels (Bailey and Maufe 1960) has been tentatively assigned, on pollen analysis, to the later Atlantic or Sub-Boreal stages (S. E. Durno, personal communication 1966). Though the post-Glacial beach is strictly outside the terms of this communication, some comment is necessary for the sake of completeness.

Late-Glacial Beaches. Late-Glacial beaches occur in the coastal areas, seaward of the limits shown on Fig. 1. For the most part they form sloping terraces and banks of shingle and sand which reach to a levelled height of 135 ft (41 m) O.D. between Arisaig and Morar, but possibly up to 150 ft (46 m) in the same area. The banks and terraces of shingle were probably laid down rapidly but intermittently while the sea-level was steadily falling, and are probably related to the supply of material available for redistribution in the vicinity of glacier snouts.

In view of the isostatic readjustment of the land following the disappearance of its ice cover, it is to be expected that the late-Glacial beaches are deformed, as is the post-Glacial beach in the same area, and the late-Glacial beaches farther south (Wright *in* Bailey and others 1924; McCann 1966a; Synge and Stephens 1966), though there is admittedly no good evidence for this in the

West Highland area. Since the beaches occur as shingle banks in conditions of varying exposure to marine processes, identification of a regional slope would in any case be difficult or impossible. Some details illustrating various features of the late-Glacial beaches follow.

In Knoydart (Arisaig (61) Sheet), terraces along the Inverie river occur at 104 ft (31·5 m) O.D. and possibly 115 ft (35 m) O.D., associated with washed-over morainic deposits. South of Loch Nevis high level beaches are present at Mallaig, and at Morar village reach a height of about 85 ft (26 m) O.D. These beaches, together with many of those farther south occur in hummocky rocky terrain, and their distribution is thus very patchy.

West of Kinloid [662 880] (Fig. 4) small banks of well-sorted gravel reach to 130 to 135 ft (39–41 m) O.D., and at three localities gravel bars are preserved at lower levels. Inland, the higher beaches disappear and at Sunisletter [NM 680 893] a terrace at about 80 to 85 ft (25–26 m) is composed of deltaic outwash gravel (p. 51). About half a mile west of Kinloid a sand and gravel bank (possibly of post-Glacial age) reaches 46 ft (14 m) O.D. The western part of the Mointeach Mhor is underlain by beach deposits, probably mainly post-Glacial. Beach gravels reach possibly up to 150 ft (46 m) north of Arisaig, and between 100 and 150 ft (30·5 and 46 m) on the south shore of Loch Ailort. A small, but well-preserved beach bar occurs at one locality [NM 716 804] on the north side of the loch, above 100 ft O.D. In Ardnamurchan and parts of Morvern, late-Glacial beach accumulations are uncommon, probably owing to the lack of glacial drift for redistribution and to distance from contemporary ice fronts, but deposits reaching up to and over 110 ft (33·5 m) O.D. are present in Glen Cripesdale on the south side of Loch Sunart (Fig. 1). North of Loch Aline a high raised beach associated with morainic mounds is present; some of the deposit at the mouth of Gleann Geall is of boulder gravel with boulders ranging up to 6 ft by 8 ft (2 m × 3 m).

On Loch Eil side Messrs. Johnstone and Wright have found traces of a beach at 47 to 52 ft (14·3–15·8 m) O.D. above the post-Glacial beach at about 40 ft (12 m) O.D. Whether or not this is a marine feature is uncertain, but if so it is the only example of a late-Glacial beach found within the area of the Loch Lomond Readvance, and later than this episode.

Post-Glacial beaches. The post-Glacial beach (formerly known as the '25-ft beach) is well seen around the West Highland seaboard. Where best developed it takes the form of a sandy or shingly platform backed by a low cliff with caves. In places beach bars are present, or, where a deposit is absent, a rock platform rises above high-water mark. Within a particular area the height of the back feature and deposits varies considerably according to the degree of exposure of the coast to marine processes, and in places more than one beach feature is present. Thus in the Morar area (Fig. 4), whilst most of the post-Glacial beach deposit is at 30 to 32 ft (9–9·7 m) O.D., contemporary storm beach bars range up to 46 ft (14 m) O.D., and a lower feature is present at 17 ft (5·2 m) O.D. near the mouth of the Allt Cam Carach. In the writer's opinion the assignment of a specific height to any sector of the post-Glacial beach on this part of the Highland sea-board (McCann 1966a) is subject to much uncertainty even after considerable selection of data. It can be said, however, that in general terms the values are lower than those found, for instance, in the sheltered inland waters of Loch Eil (about 40 ft, 12 m O.D.). A possible solution to the problem would be to level the lower terrace of Loch Shiel (mapped as lacustrine on the One-inch Tobermory (52) Sheet but probably marine, see McCann 1966b), thus providing a record eastwards from the west coast of features formed under comparable conditions of marine processes.

Discussion

At some stage during the Weichselian, ice crossed the western part of the West Highland District from an ice-shed situated well to the east of the present watershed, and probably some distance to the east of the ice-shed at the last stage of glaciation. A large ice-stream in Loch Linnhe was deflected north-westwards across Morvern and Ardnamurchan, and farther north a westward flow of ice crossed Arisaig, Morar, Knoydart, and the southern part of Skye. Little evidence of this stage has been found east of the Great Glen, but it appears that erratics of the granitic rocks at the north end of the Loch Treig valley (outwith the district) are dispersed across the hills to the north and north-west (Tenth and Final Report of the Boulder Committee, 1884, p. 826), suggesting that any ice entering Glen Spean from the west was diverted up Glen Roy, or over the high ground between Glen Roy and the Great Glen.

Following the stage of (local) maximum glaciation, evidence is lacking until a time when the ice in the western valleys was probably in contact with the late-Glacial sea, which rose relative to the land to between 100 and 150 ft O.D. on the west coast. The evidence for this period is largely negative in West Inverness-shire being inferred from the absence of the highest beaches from the inner part of the sea lochs. Detailed work in the ground north of Loch Nevis would probably provide considerably more data on this subject. Whether there was a readvance of ice at this period or a stillstand following the retreat from the maximum is not clear.

As the ice withdrew farther into the valleys the sea-level gradually fell, the result being that the lower late-Glacial beaches are found some distance to the east of the highest beach.

At the time of the maximum of the Loch Lomond Readvance, the ice front apparently lay at Corran Ferry in Loch Linnhe, and ice-fronts of probably contemporaneous age at the west ends of Loch Shiel and Loch Morar (McCann 1966b). The height of the late-Glacial sea at this stage is not everywhere easy to assess. There is little doubt that at Corran Ferry it stood at, or below, the level of the post-Glacial beach (McCann 1966b). At the west end of Loch Shiel, E. B. Bailey envisaged that the outwash fan was laid down sub-aerially (*Summ. Prog.* for 1922, p. 76), but at a later date he was willing to adopt a hypothesis of marine deposition (A. G. MacGregor, Geological Survey records 1955). The virtual absence both of late-Glacial beach gravels outside the fan area in Kentra Bay and of signs of deltaic sedimentation in the admittedly poorly exposed fan gravels (p. 48) is, however, more in keeping with Bailey's earlier view.

J. E. Richey concluded that the advance of the Morar glacier to the west end of the loch, or its stillstand about this position, was contemporaneous with a sea-level of about 50 ft (15·2 m) O.D. (*Summ. Prog.* for 1936, p. 76), but McCann (1966b, p. 91) states that there is no evidence for this view, the gravels south-west of Camas Ruadh having been deposited as sub-aerial outwash fan. The relationship and distribution of the superficial deposits are however more complex than envisaged by McCann (Fig. 4, and pp. 51 and 53 of this account), and there is sketchy evidence for two glacial stages, the earlier contemporary with a late-Glacial sea standing at about 80 ft (24 m) O.D. (Sunisletter terrace), and the later to a sea-level near or below that of the highest post-Glacial beach. The sub-aerial outwash gravels of the later (Loch Lomond Readvance) stage are probably restricted to within a mile of Camas Ruadh, and to the area about the intake of the River Morar. It is of interest that at Morar the Loch Lomond Readvance ice almost reached the position of the earlier ice front corresponding to the highest late-Glacial beaches.

The glacier terminations of the Loch Lomond Readvance ice at localities without outwash are difficult to define since no other terminal features occur; they may have been, very roughly, near the eastward limit of late-Glacial beach deposits as represented on Fig. 1.

Recent estimates suggest an interval of about 500 years for the cold period which gave rise to the Loch Lomond Readvance, and 1200 years for the preceding milder interval, the Alleröd Oscillation (e.g. West 1968). Though it has been suggested that ice may have disappeared from Scotland during the Alleröd (Sissons 1967), it is difficult to understand how the great volume of ice stored in the Arkaig/Kingie ice caps and in the other large valley glaciers could have accumulated in only 500 years. The writer therefore supports the view of Manley (1959), based on palaeoclimatic data, that active glaciers were present in the Highlands during the Alleröd period.

Conclusions

Following a period of retreat from a time of 'maximum' glaciation, during which ice from Loch Linnhe crossed Morvern and Ardnamurchan, it is inferred that sea-level rose relative to the land surface to a maximum of between 130 and 150 ft (40 and 46 m) above present-day sea-level. During the Loch Lomond Readvance small ice caps were centred near the heads of Loch Arkaig and Glen Kingie, and the principal ice-shed lay a few miles east of the main Scottish watershed. The ice-shed controlled the development of the features and melt-water deposits at the heads of the major west–east valleys during the subsequent disappearance of the glaciers.

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III.—A REVIEW OF THE BRACHIOPOD GENUS *CRANIA* IN THE SCOTTISH CARBONIFEROUS

BY

D. K. GRAHAM

Plates III–IV; Text-figure 1

Summary. The wide range of morphological variation shown by *Crania* in the Scottish Carboniferous is discussed and illustrated. This variation is attributed to environmental factors rather than to genetic ones. It is concluded that *Crania quadrata* (McCoy), 1844 is a junior synonym of *Crania ryckholtiana* (de Koninck), 1843.

INTRODUCTION

CRANIA IS A calcareous-shelled, inarticulate brachiopod. It is non-pedunculate and attaches itself to the surface of another marine organism, or to a rock, by cementation of the entire area of one of its valves. This valve is termed the attached valve throughout the paper as the expressions 'pedicle valve' and 'ventral valve' used by some authors are inaccurate with reference to *Crania*. The attached valve is basically flat but because of the nature of its attachment it adopts, to a large extent, the form of the surface to which it is cemented. The brachial valve is essentially conical.

The genus is comparatively rare in the Scottish Carboniferous but has a long stratigraphical range extending from the Palaeozoic to the present day. The type species, *Crania craniolaris* (Linné), is of Cretaceous age.

Several Carboniferous species of *Crania* have been described but only two, *C. ryckholtiana* (de Koninck) (1843, p. 327, pl. 23, fig. 5a, b) and *C. quadrata* (McCoy) (1844, p. 105, pl. 20, fig. 1), appear to have been widely recognized in European literature. Unfortunately it has not been possible to trace the type material of either of these species and comparisons must depend solely on the original figures which are poor and on the descriptions which are inadequate. The wide variety of forms figured by later authors, and ascribed to one or other of these species, has further confused the position. Identification of Scottish forms has consequently proved exceedingly difficult.

A study of about two hundred specimens of *Crania* from the Scottish Carboniferous revealed considerable variations in the forms present. In many cases this was clearly the result of external influences, but in others it was difficult to distinguish the effects of such influences from genuine genetic variations. In the ensuing discussion the significance of external factors in morphological variation is considered.

The author wishes to thank Dr. C. D. Waterston of the Royal Scottish Museum, Edinburgh, for access to specimens in his charge. All the material used in this study is housed in the Royal Scottish Museum (RSM) and in the Edinburgh office of the Institute of Geological Sciences (GSE).

MORPHOLOGICAL VARIATION

Most of the specimens of Carboniferous *Crania* studied consist of attached valves with the whole of their external surfaces adhering intimately to crinoid columnals or to marine shells. Of the latter form of host body brachiopod shells are by far the most common. Modern *Crania* are attached by cementation to another object and examination of Carboniferous forms suggests a similar mode of attachment.

Observations indicate that no preferred orientation was adopted by young *Crania* in relation to the host body on initial attachment. Subsequent growth was therefore subject to the configuration of the host surface, together with physical limitations such as the maintenance of an adequate size of body chamber, and the ability to open and close the valves. Where minor irregularities occurred on the surface of the host body these were accommodated by local adjustments in the thickness of the attached valve. More prominent features, such as the coarse costae of spiriferoid shells, were tolerated by flexure of the valves, and attachment to the external surface of any ribbed brachiopod generally resulted in the occurrence of strongly corrugated forms. Where the surface of the host was strongly rounded, or where there was overcrowding of the *Crania* valves, considerable distortion is common. In such cases it is generally obvious that the resultant forms are distorted (Plate IV, figs. 3, 4, 8 and 11).

Most of the specimens studied are, however, attached to crinoid columnals, and in such occurrences distortion can be more difficult to detect. It was found that, regardless of their orientation, many valves were extended along the length of the supporting columnals, whereas protraction around the columnals was never observed. Where the anterior–posterior axis of the valve is oblique to the long axis of the columnal (Plate IV, fig. 10), distortion is clearly visible. Where, however, these axes are parallel, or at right angles, the resultant extension produced long, or broad, symmetrical forms (Plate IV, fig. 2). Such specimens are markedly different in outline and could well be placed in different species if the cause of the variation was not apparent.

In some specimens it was found that although their axes were parallel, or at right angles, to the long axes of the columnals, and protraction was directed along the latter, the forms which resulted are asymmetrical (Plate IV, figs. 1, 6, 7 and 9). In these cases termination of growth in one direction appears to have coincided either with a break in the columnal (Plate IV, figs. 1, 9), or with a sudden flexure of the surface of the columnal where branching had occurred (Plate IV, figs. 6, 7). In cases where such obstacles were sufficiently small the valve was able to override them (Plate IV, fig. 11).

The occurrence of extended forms on crinoid columnals suggests that such forms were preferable to ones in which there was excessive reflexing of the attached valve. Considerable degrees of reflexing have been observed, but must presumably have been limited by the difficulty of maintaining an adequate size and shape of body chamber in the forms produced. This would account for the fact that protraction is greatest where the supporting crinoid columnals are very slender. The presence of *Crania* on the inner surfaces of brachiopod shells and on the ends of crinoid columnals confirms that valves did grow on empty shells and dissociated columnals, but no evidence has been found that Carboniferous *Crania* could adhere to living crinoids. If, however, this type of attachment was possible, the growth pattern of the valves may well have been influenced by differences between their own rates of growth and those of the columnals.

It is concluded that it was necessary for Carboniferous *Crania* to remain, during growth, in intimate contact with the surfaces to which they had initially become attached. In achieving this, conformity to a genetically controlled valve-shape was sacrificed in many individuals. The evidence also points to a strong preference for maximum growth to follow directions approaching nearest to a plane surface.

Observations on available material indicate that little importance can be attached to comparisons of convexity and contours of the brachial valve which, like the attached valve, is influenced by irregularities on the surface of the host body and, in any case, rarely occurs uncrushed.

SYSTEMATIC PALAEONTOLOGY

Superfamily: CRANIACEA Menke, 1828

Family: CRANIIDAE Menke, 1828

Genus: CRANIA Retzius, 1781

Crania ryckholtiana (de Koninck)

Patella ryckholtiana de Koninck, 1843, p. 327, pl. 23, fig. 5a, b.
Crania vesiculosa McCoy, 1844, p. 105, pl. 20, fig. 3.
Orbicula quadrata McCoy, 1844, p. 104, pl. 20, fig. 1.
Orbicula ryckholtiana de Koninck, 1851, p. 669, pl. 56, fig. 12.
Orbicula truncata de Koninck, 1851, pp. 668–9, pl. 56, fig. 11.
Crania quadrata: Davidson, 1860, pp. 223–5, pl. 4, figs. 12–21.
Crania quadrata: Davidson, 1861, pp. 194–5, pl. 48, figs. 1–13.
Crania ryckholtiana: Davidson, 1861, pp. 195–6, pl. 48, figs. 15–7.
Crania ryckholtiana: Demanet, 1934, pp. 31–6, pl. 1, figs. 23–31.
Crania quadrata: Demanet, 1934, p. 36, pl. 1, figs. 32, 33.
Crania ryckholtiana: Reed, 1954, p. 181, pl. 1, fig. 1.

Description. It has been shown that most *Crania* are deformed in some way as a result of ecological factors and the outlines of the valves shown in Fig. 1 should be regarded as the forms which would occur under ideal conditions rather than those most commonly encountered. Fig. 1 is a composite diagram derived from the valves illustrated in Plate III, figs. 2–5. Ideally, therefore, the outline may be described as sub-circular narrowing posteriorly, with a slightly truncate posterior margin which is almost straight or gently concave. The postero-lateral margins, where discernible, are short and may be gently convex, straight, or slightly concave. The lateral margins are convex and merge imperceptibly with the less strongly rounded anterior margin. The breadth is generally slightly greater than the length which, in specimens believed to be mature, averages about 10 mm. The attached valve is flat and is generally thin-shelled except at the margins, but local areas of thickening may be present where there has been accommodation to irregularities in the surface to which the valve is attached. The shell of the brachial valve is considerably thicker and is strongly punctate, the canals branching towards the outer surface (Plate III, figs. 8, 9). The brachial valve is strongly convex and sub-conical, the apex being a little posterior of its centre. The external surface is rough and is marked by coarse, irregular, stepped, concentric growth lines and by small depressions at the outer ends of the canals which are clearly visible under magnification.

Explanation of Plate III

For abbreviations for depositories see p. 57.

Figs. 1–9. *Crania ryckholtiana* (de Koninck).

Figs. 1, 1a. RSM 1911.62.3131, x 3, exterior (1) and interior (1a) of brachial valve' Thornliebank, Glasgow, Upper Limestone Group (E_2).

Figs. 2, 2a. RSM 1911.62.3132, x 3, exterior (2) and interior (2a) of brachial valve, Thornliebank, Glasgow, Upper Limestone Group (E_2).

Fig. 3. GSE 12694, x 3, interior of attached valve, Auchentibber near East Kilbride, Lower Limestone Group (P_2).

Fig. 4. RSM 1884.46.267b, x 3, interior of attached valve figured by Davidson 1860, pl. 4, fig. 14, from one of a group of quarries near East Kilbride, ?Lower Limestone Group (P_2).

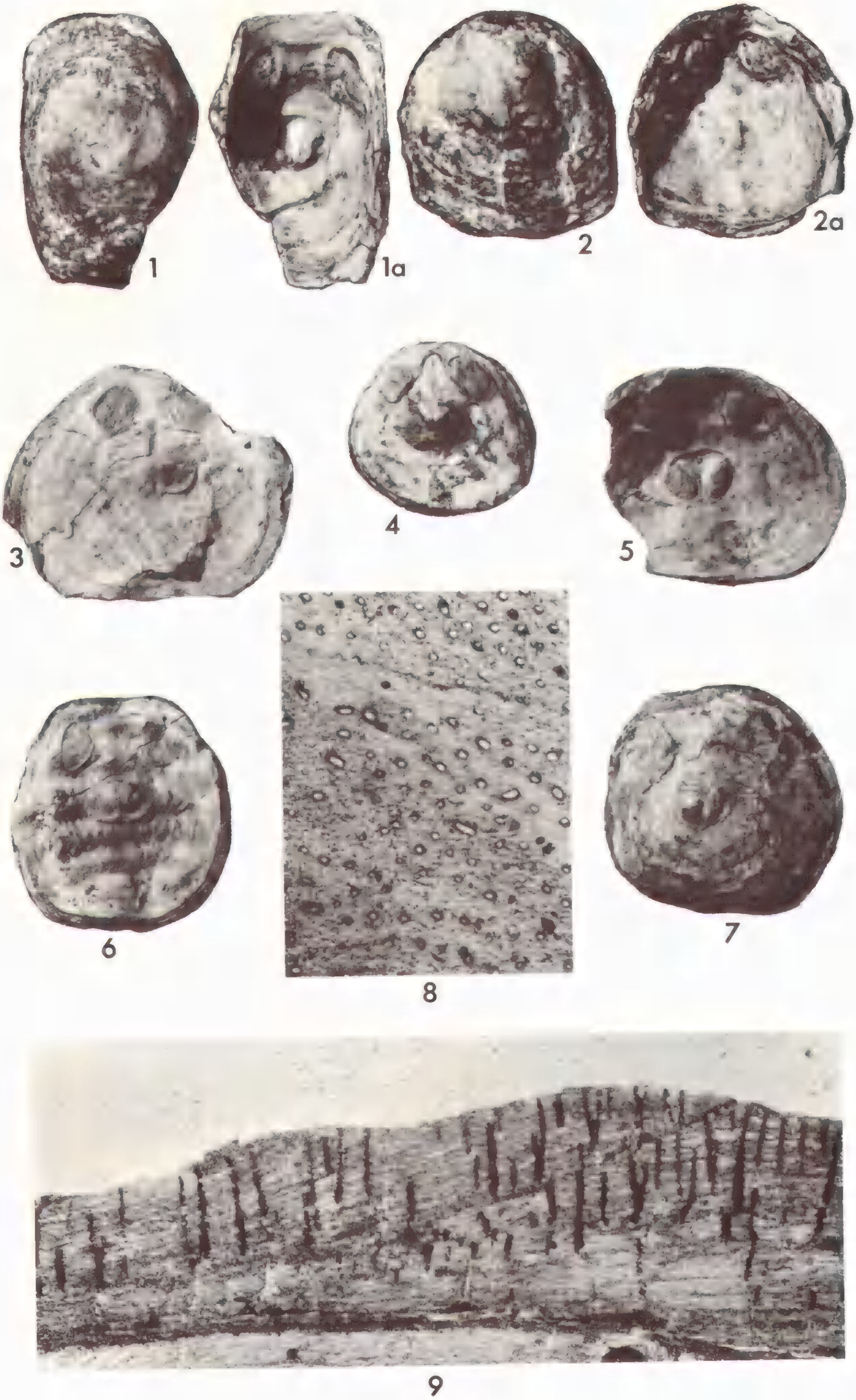
Fig. 5. GSE 12702, x 3, interior of brachial valve, locality and horizon as for Fig. 4.

Fig. 6. RSM 1884.46.267c, x 3, interior of attached valve, locality and horizon as for Fig. 4.

Fig. 7. RSM 1884.46.264c, x 3, exterior of brachial valve, locality and horizon as for Fig. 4.

Fig. 8. GSE PS3114, x 100, tangential section of brachial valve, Boghead, near Hamilton, Lanarkshire, Lower Limestone Group (P_2).

Fig. 9. GSE PS3112, x 100, transverse section of both valves showing partial infilling by pyrite of the canals and of the interspace between the attached valve and the considerably thicker brachial valve, Auchentibber, near East Kilbride, Lower Limestone Group (P_2).



SCOTTISH CARBONIFEROUS *CRANIA*

SCOTTISH CARBONIFEROUS *CRANIA*

Explanation of Plate IV

For abbreviations for depositories see p. 57.

Figs. 1–11. *Crania ryckholtiana* (de Koninck).

Fig. 1. GSE 12698, x 3, attached valve showing asymmetrical protraction, growth in one direction arrested at the end of the columnal, Boghead, near Hamilton, Lanarkshire, Lower Limestone Group (P_2).

Fig. 2. GSE 12696, x 3, attached valve with anterior–posterior axis at right angles to the columnal, showing resultant symmetrical broad form, Orchard, Glasgow, Upper Limestone Group (E_2).

Fig. 3. GSE 12699, x 3, attached valves showing longitudinal protraction and also distortion by overcrowding, Brankumhall, near East Kilbride, Lower Limestone Group (P_2).

Fig. 4. RSM 1911.62.3146, x 3, brachial valves, slightly distorted, on a brachiopod, Capelrig, near East Kilbride, Lower Limestone Group (P_2).

Fig. 5. GSE 12695, x 3, attached valve showing long axis slightly oblique to that of the columnal resulting in an elongate imperfectly symmetrical form, Auchentibber, near East Kilbride, Lower Limestone Group (P_2).

Figs. 6–7. RSM 1884.46.264a, x 3, attached valves with anterior–posterior axes almost at right angles to the long axis of the columnals, protuberances on which inhibit and deflect growth of *Crania*, locality unknown.

Fig. 8. RSM 1884.46.264b, x 3, attached valves showing distortion due to overcrowding and convexity of host, locality unknown.

Fig. 9. RSM 1884.46.265a, x 2, attached valves showing only slight protraction when attached to thick columnals, with growth arrested at the end of the columnal, as in Fig. 1, Capelrig, near East Kilbride, Lower Limestone Group (P_2).

Fig. 10. RSM 1884.46.265c, x 3, attached valve showing marked asymmetry where the anterior–posterior axis is oblique to the long axis of the columnals, Capelrig, near East Kilbride, Lower Limestone Group (P_2).

Fig. 11. GSE 12714, x 6, brachial valve showing accommodation to irregular surface of the columnal, Brankumhall, near East Kilbride, Lower Limestone Group (P_2).

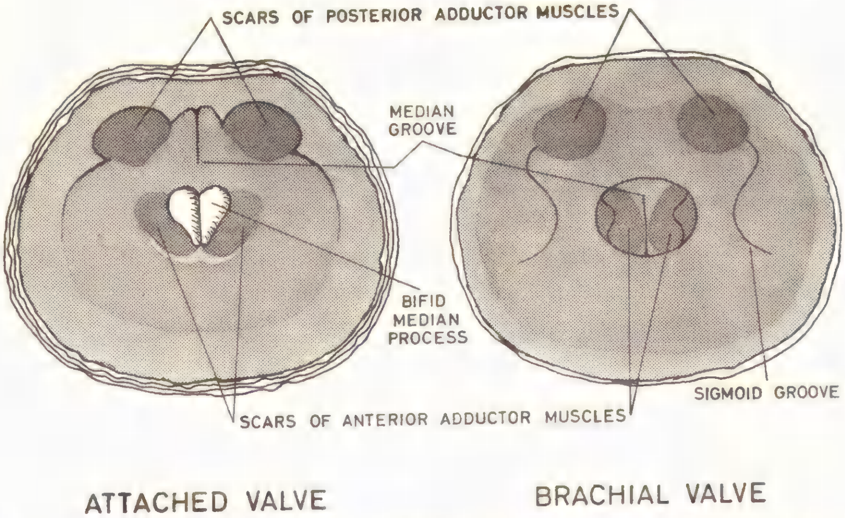


FIG. 1. *Internal shell surfaces of attached and brachial valves of* Crania ryckholtiana *(de Koninck) showing features observed. The valves illustrated are not from the same specimen*

The internal surfaces of both valves are smooth and the punctae on the brachial valve are clearly displayed. The anterior and posterior adductor scars in the form of elevated or depressed areas are prominent (Fig. 1). Scars of the smaller muscles, as depicted by Williams and Rowell (*in* Moore 1965, p. H29, fig. 29.2), have not been conclusively observed in any of the specimens examined during this study. The shapes of the scars which can be seen vary appreciably between individuals but their sizes and positioning are reasonably consistent. The posterior adductors are situated near to the posterior margin where, in some cases, mainly in attached valves, slight postero-lateral protrusions of the shell are developed. The anterior adductor scars are situated a little posterior to the centre of the valve and differ in the two valves. Those of the brachial valve diverge posteriorly from the median axis of the valve and, in some of the examples studied, are surrounded by a shallow groove, or corrugation, bisected by a short median groove (Fig. 1). In the attached valve the scars are inclined against a sharply elevated, bifid, heart-shaped process. Near the margin of the attached valve a broad flattened zone surrounds a depressed central area. This zone becomes wider in the postero-lateral parts of the valve, partially enclosing the posterior adductor scars, between which it recedes leaving a U-shaped cavity divided by a median groove which, in some valves, extends anteriorly to the centre of the shell. A corresponding but narrower zone is present in the brachial valve where, in the examples observed, it does not appear to enclose the posterior adductor scars. Faint vascular markings are present in some cases and a pair of sigmoid grooves extending anteriorly from the posterior adductor scars of the brachial valve has been observed in one specimen (Fig. 1).

Discussion. When de Koninck (1843, p. 327, pl. 23, fig. 5a, b) erected the species *ryckholtiana* he referred it to the genus *Patella* Linné, 1758, but in a later work (1851, p. 669, pl. 56, fig. 12) he re-ascribed it to *Orbicula* Cuvier, 1798. It is now generally accepted (Muir-Wood 1955, p. 6) that *Orbicula* is a junior synonym of *Crania* Retzius, 1781, but the two were regarded as separate genera by early authors. This gave rise to much confusion. McCoy (1844, pp. 104, 105), describing three new species referred two, *quadrata* (op. cit., p. 104, pl. 20, fig. 1) and *trigonalis* (op. cit., p. 104, pl. 20, fig. 2), to *Orbicula*, but referred the third, *vesiculosa* (op. cit., p. 105, pl. 20, fig. 3), to *Crania*.

De Koninck (1851, pp. 668, 669, pl. 56, fig. 11) described another species, *Orbicula truncata*, and (op. cit., p. 669) placed *Crania vesiculosa* McCoy in synonymy with *Orbicula ryckholtiana* de Koninck. Davidson (1860, pp. 223, 224) referred *ryckholtiana*, *truncata* and *quadrata* to *Crania*, but recognized only *Crania quadrata* in the Scottish Carboniferous. Davidson (1861, p. 195) supported de Koninck's opinion that *ryckholtiana* was conspecific with *vesiculosa* but mistakenly named the latter *C. vesicularis*. Davidson (op. cit., p. 196) doubtfully referred *Orbicula trigonalis* McCoy to *Crania*, and the species has recently been ascribed by Brunton (1968, p. 8) to the genus *Philhedra* Koken, 1889.

Demanet (1934, pp. 30–36), in a revision of Belgian Dinantian forms, examined the species erected by de Ryckholt (1847, pp. 93–8, pl. 4, figs. 7–24, pl. 5, figs. 1–4). He concluded that the species *Orbiculoidea hieroglyphica* de Ryckholt, *O. gibbosa* de Ryckholt, and *O. tortuosa* de Ryckholt should correctly have been ascribed to *Crania* and placed them in synonymy with *Crania ryckholtiana*. Demanet also regarded *Orbicella psammorpha* de Ryckholt and *Orbicula obtusa* de Ryckholt as *Crania*, but referred those forms to *Crania quadrata*.

The first reference to the occurrence of *Crania ryckholtiana* in the Scottish Carboniferous was by Reed (1954, p. 181) who described specimens from the Lower Limestone Group (P_2) east of St. Monance, Fife.

Williams (1943, pp. 69–72) recognized three forms within the genus *Crania*, which he subdivided into three sub-genera, *Crania* s.s., *Acanthocrania* and *Lissocrania*. He restricted his definition of *Crania* s.s. to radially costate forms and assigned smooth-shelled species to *Lissocrania*. Williams considered all three sub-genera to be present in the Carboniferous and gave the range of the genus as Ordovician to Recent (1943, p. 69). Rowell, however, (*in* Moore 1965, p. H290) would appear to have doubted the propriety of placing Carboniferous forms in *Crania* and recorded its range as ?Carboniferous, Cretaceous–Recent.

Brunton (1968, p. 5) commented that both *Crania craniolaris* (Linné), the type species, and the modern *Crania anomala* (Müller) are devoid of radial ribbing and regarded the retention of *Lissocrania* as therefore unjustified. Brunton felt that the differences between Carboniferous and Cretaceous forms might, however, be sufficient to merit their inclusion in separate genera. He suggested that a clearer understanding of the genus *Philhedrella* Kozlowski, 1929, might indicate that Palaeozoic forms presently referred to *Crania* should be, more appropriately, referred to *Philhedrella*. In a description of the species *quadrata*, however, Brunton retained the generic name *Crania* and in the absence of more positive evidence to the contrary it is concluded that this genus is still valid for Carboniferous species.

The inadequacy of the figures and descriptions of the two species most widely cited in British and Western European literature makes it particularly unfortunate that the type specimens of *Crania quadrata* and *Crania ryckholtiana* have not been traced. Although de Koninck's figure (1851, pl. 56, fig. 12) does not establish conclusively that *ryckholtiana* is a species of *Crania*, the specimens observed by him were attached to other shells in what he described as a parasitic manner. It is unlikely therefore that the figured valve would belong to the Discinidae, a family in which attachment is by means of a pedicle, and valves apparently adhering intimately to other shells are exceptional in their occurrence.

In his description of *Crania quadrata* McCoy gave one figure only. This figure was also inconclusive. The position was not clarified by the fact that, although McCoy's description of *Crania* and *C. vesiculosa* (1844, p. 105) showed his familiarity with that genus, he referred *quadrata* to *Orbicula*, which he described as having a pedicle valve perforated for byssal attachment. Fortunately, Davidson (1861, pl. 48, fig. 2) was able to re-figure the original specimen showing the brachial valve not only more convincingly, but adhering to a crinoid stem upon which it was accompanied by an attached valve undoubtedly belonging to a *Crania*.

McCoy's figure of *Crania quadrata* shows a flatter and less rounded shell than *Crania ryckholtiana* as described by de Koninck, but it has been shown that Carboniferous *Crania* are highly susceptible to distortion in outline and convexity, and the author is unable to agree with the opinions expressed by de Koninck (1851, p. 19), Davidson (1861, pp. 194–6) and later Demanet (1934, pp. 31, 32), that *C. quadrata* and *C. ryckholtiana* are specifically distinct.

The specimens which Demanet (1934, pl. 1, figs. 32, 33) figured as *C. quadrata* do, however, appear to be significantly different from those which he figured as *C. ryckholtiana*, but they also differ to some extent from the example shown by McCoy (1844, pl. 20, fig. 1). In both of Demanet's figures the apex is nearer to the posterior margin than in McCoy's figure, although the apex of the latter is believed to be abnormally far back for the species owing to crushing, and its position is not the same as that stated in the description. These figures, along with de Ryckholt's illustration of *Orbicula obtusa* (1852, pl. 5, fig. 1), a species which Demanet (1934, p. 36) placed in synonymy with *C. quadrata*, show a close resemblance to a poorly known group presently under study. This form appears to be comparatively rare in the Scottish Carboniferous and to have a restricted distribution. The scarcity and poor quality of material so far obtained has precluded satisfactory morphological examination, but it is questionable whether the specimens studied are in fact craniids and their correct systematic position has yet to be established.

An examination of McCoy's description and figures of *C. vesiculosa* leaves little doubt that de Koninck (1851, p. 19) was correct in placing *C. vesiculosa* in synonymy with *C. ryckholtiana*. Contrary to the opinion expressed by de Koninck (op. cit., p. 19) it seems unlikely that *C. truncata* (de Koninck) and *C. quadrata* (McCoy) are specifically distinct. It would appear, therefore, that the names *C. ryckholtiana*, *C. quadrata*, *C. truncata*, and *C. vesiculosa* are all synonyms. It is possible that certain of de Ryckholt's species should also be included in the synonymy, as suggested by Demanet (1934, pp. 31, 32 and 34), but this cannot be established conclusively from the original figures. As de Koninck's description of '*Patella*' *ryckholtiana* slightly pre-dates those of '*Orbicula*' *quadrata* and *Crania vesiculosa* by McCoy, *ryckholtiana* is the senior synonym.

It should be noted that the name *Crania quadrata* was in any case invalid. Eichwald (1829, p. 273) had applied this name to a Lower Palaeozoic species which he subsequently recognized to be a *Lingula* (1840, p. 164) and re-designated *Lingula quadrata.*

The shell structure of *C. ryckholtiana* appears to be typical of its genus and resembles that described by Carpenter (*in* Davidson 1853, pp. 37, 38) and more recently figured by Williams and Rowell (*in* Moore 1965, p. H75, fig. 77.1), but the finer arborescent branching near to the outer surface of the brachial valve has not been observed in this study. It is possible, however, that the outer shell layers were missing in the examples sectioned. Carpenter (op. cit., p. 24) stated that the upper valve in *Crania* increased in thickness and in diameter by new formations successively added to the internal surface and extending beyond the margins of the old. The shell sculpture observed in the Carboniferous forms studied suggests that in this respect also *C. ryckholtiana* is typical of its genus.

The species occurs throughout the Scottish Carboniferous with no obvious geographical restriction and appears to be of little value as a stratigraphical index fossil.

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IV.—BRITISH CARBONIFEROUS ISOGRAMMIDAE

BY

P. J. Brand, B.Sc.

Plates V–VIII; Text-figure 1

Summary. British Carboniferous species of the brachiopod genus *Isogramma* are described and discussed. Two new species, *I. salteri* and *I. scotica*, are proposed. Type specimens of *I. carinthiaca*, *I. germanica* and *I. millepunctata* are refigured.

Introduction

Isogramma Meek and Worthen, 1870, is a genus of articulate brachiopods, the type species being *Chonetes?? millepunctata* Meek and Worthen, from the Upper Carboniferous of Illinois, U.S.A. The genus ranges from the Viséan to the Permian and it is widely distributed. In the Lower Carboniferous it has been recorded from Britain, Germany, Russia and the United States (only one record) and in the Upper Carboniferous from Britain, Spain, Austria, Italy, Hungary, Russia, China and the United States.

Records of *Isogramma* from Britain are rare. Davidson (1863, pp. 278–9) identified a specimen from Fife as *Chonetes concentricus* de Koninck which he later (1884, pp. 283–4) re-identified as *Aulacorhynchus davidsoni* Barrois. Lee (*in* Richey and others 1930, p. 244) identified specimens from North Ayrshire as *A. davidsoni*. Other records of the genus are those of Stubblefield (*in* Fowler and Robbie 1961, p. 52 footnote; 1963, p. 11), Wilson (1962, p. 55) and Stubblefield (1963, p. 11; see also Green and Welch 1965, p. 27). No new species have been described from British material. In recent years new material has become available from various parts of Britain and this has formed the basis of the present study, together with previously recognized specimens.

For comparative purposes attempts were made to trace the type specimens of a number of species. The author wishes to thank the following for photographs of, or the loan of, specimens in their care: Dr. J. Carter, University of Illinois; Dr. H. W. Flügel, Graz University; Dr. H. Jaeger, Humboldt University, Berlin; Dr. C. D. Waterston, Royal Scottish Museum and Dr. A. Wattison, Anstruther.

Previously Described Species

Lower Carboniferous

I. carinthiaca Aigner (1931, pp. 8–10), Austria; here refigured (Plate V, figs. 14, 16).

I. chernyshevi Aizenverg (1964, pp. 147–8), Ukraine.

I. germanica Paeckelmann (1930, pp. 211–3), Austria, Germany, Lower Moscow basin and the Ukraine; here refigured (Plate VI, figs. 10, 11).

I. licharevi Aizenverg (1964, pp. 151–2), Ukraine.

I. paeckelmanni Aigner and Heritsch (1931, pp. 313–4), Austria, Ukraine.

I. paeckelmanni donbassica Aizenverg (1964, pp. 149–51), Russia. (Also occurs in the lower part of the Upper Carboniferous, Russia.)

UPPER CARBONIFEROUS

I. davidsoni (Barrois) (1882, pp. 326–9), Spain.
I. expansa (Gortani) (*in* Vinassa and Gortani 1905, p. 534), Austria, Hungary and Italy.
I. kahlerorum Gauri (1965, pp. 30–1), Austria.
I. millepunctata (Meek and Worthen) (1870, pp. 35–6; 1873, pp. 566–9), Russia, U.S.A. (Also occurs in the Permian, U.S.A.); here refigured (Plate VI, figs. 5, 6).
I. pachti (Dittmar) (1872, pp. 2–6), Russia, U.S.A.
I. paotechowensis (Grabau and Chao) (*in* Chao 1928, pp. 33–5), Austria, China and Russia. (Also occurs in the Permian, Japan, Russia.)
I. renfrarum Cooper (1952, pp. 114–5), U.S.A.
I. texanum Cooper (1952, pp. 115–7), U.S.A.
I. ussensis (Dittmar) (1872, pp. 12–3), Russia.
I. zoellnerensis Gauri (1965, pp. 29–30), Austria.

PERMIAN

I. heritschi Nakamura (1970, pp. 308–10), Japan.
I. paotechowensis pokrowskiensis Menshagin (1936, pp. 51–3), Russia.

These species exhibit a wide variety of form, from the very large transverse species such as *I. renfrarum* to the small ones such as *I. pachti*. Also included are two forms with radially folded brachial valves, *I. paeckelmanni* and *I. paeckelmanni donbassica*. Gauri (1965, p. 27) suggested that the degree of variation of the cardinal process and of the breviseptum shown by various species of *Isogramma* merits a reclassification with the introduction of new genera. Lack of sufficiently well-preserved material, however, prevented him from proposing such a scheme.

Although of infrequent occurrence in the stratigraphical column, *Isogramma*, if present at a locality, is usually found in large numbers, suggesting that the genus was gregarious. British specimens occur in a range of lithologies, from calcareous sandstones, to mudstones and limestones, and a similar range of lithologies is recorded elsewhere.

MORPHOLOGY

The general features of the morphology of the genus are shown in Fig. 1. The terminology of some of the parts is derived from Muir-Wood and Cooper (1960, pp. 3–8) and notes on some of these terms are given below.

Cardinal process. (Fig. 1d). The cardinal process comprises the shaft and myophore together with buttress plates where present. Muir-Wood and Cooper (1960, p. 7) define the myophore as the lobate roughened face of the cardinal process, or surface of attachment of the diductor muscles. According to Gauri (1965, p. 28) the myophore may be monolobed or trilobed; although on apparently similar specimens of *I. donbassica* (p. 71) from Scotland the myophore may appear monolobed or trilobed. This may be a reflection of the poor development of the lobes combined with poor preservation of the specimens.

The shaft is the more anterior part of the cardinal process, supporting the myophore. It is variably developed in the genus; in *I. salteri* sp. nov. the shaft is more or less absent, whilst in *I. expansa*, as described by Gauri (1965, p. 29), the shaft is long.

Buttress plates are plates located on either side of the shaft and anterior to it. The type specimens of *I. millepunctata* show the presence of buttress plates,

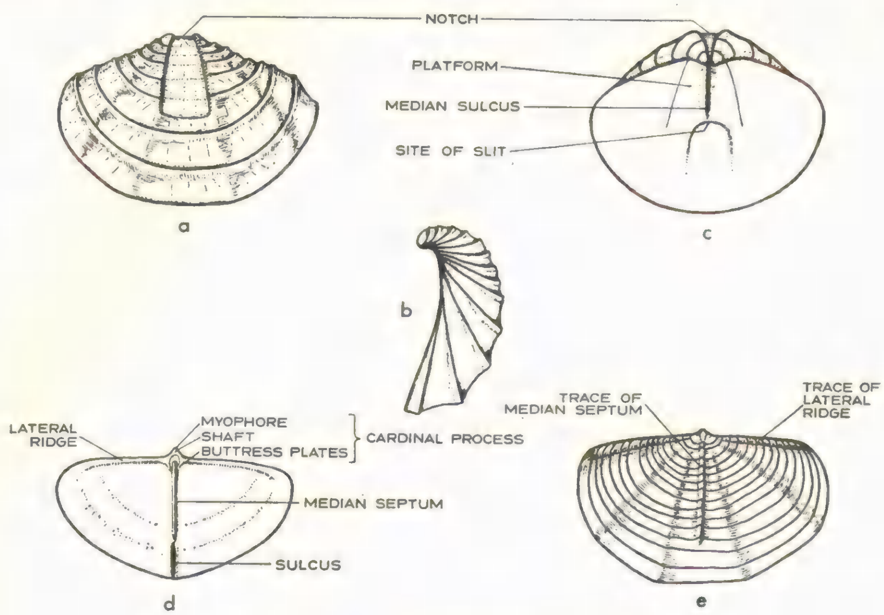

FIG. 1. *General morphology of Isogramma*

a. *I.* cf. *germanica*, pedicle valve exterior showing position of notch. **b.** *I.* cf. *germanica*, pedicle valve exterior showing degree of involution of pedicle umbo. **c.** *I. salteri* sp. nov., pedicle valve interior. **d.** *I. pachti*, brachial valve interior. **e.** *I. donbassica*, brachial valve exterior.

and apart from Scottish specimens of *I. donbassica* other species of *Isogramma* show buttress plates where these internal details are known. These plates enclose the posterior end of the median septum [breviseptum of Muir-Wood and Cooper (1960, p. 4)].

Interarea. Muir-Wood and Cooper (1960, p. 6) defined an interarea as the plane surface of the palintrope, that is, that part of the shell growing from the posterior margin in a direction opposite to that of normal shell growth. In *Isogramma* this is variably developed. The photographs of the type specimens of *I. millepunctata* do not show if an interarea is present, and Dunbar and Condra (1932, p. 282) in their description of the species stated that there are no interareas in either valve. However *I. paotechowensis* for example possesses a well-developed interarea.

Lateral ridges. (Fig. 1d). Muir-Wood and Cooper (1960, p. 6) defined lateral ridges as rounded thickenings or ridges in the brachial valve extending laterally from the cardinal process and probably serving as an accessory form of articulation. In *Isogramma* there are no teeth or sockets, and it seems probable that these ridges form the principal means of articulation of the shell itself. The position of the lateral ridges and the median septum are often recognizable on moulds of the external surface (Fig. 1e), as though they had been pressed through, a feature noted by Meek and Worthen (1870, p. 35).

Musculature. The musculature of both valves is not well known. Barrois (1882, p. 327) suggested that the adductor and diductor scars in the pedicle valve were confined to the platform. Cooper (1952, pp. 116–7), however, suggested that the diductor scars were broad and flabellate, situated on either side of the platform. The scars on the platform were regarded by him as adductor scars. The musculature of the brachial valve is even less well known. Although Dittmar (1872, pl. 1, fig. 3) showed a brachial valve of *I. pachti* with a pair of scars on either side of the median septum, Cooper (1952, p. 117) suggested that these scars were farther from the septum than might be expected in brachiopods. One specimen of *I. pachti* from Scotland shows narrow, laterally elongate crescentic scars extending from either side of the median septum, in a similar position to Dittmar's original figure (Plate V, fig. 1). Other specimens, however, do not show these scars.

Notch. (Fig. 1a, c). The notch is a smooth triangular depressed area on the external surface of the pedicle valve extending from close to the umbo towards the anterior. Its lateral margins are well defined. Specimens of *I. salteri* exhibit some variation in the ratio shell length/notch length in similar sized valves, and a juvenile specimen (Plate V, fig. 15) shows the notch area nearly covered by the outer shell layer, although the trace of the notch margins extends to about halfway across the valve. It seems possible that in this species very young individuals may not possess a notch.

On adult shells the posterior end of the notch is ill defined and may be filled with callus flush with the intervalleys between the ridges. The anterior end of the notch, according to Dittmar (1872, pp. 4–5), connects with the interior of the shell by way of a narrow oblique slit. Dunbar and Condra (1932, p. 283) stated that the platform rested on septa in this slit.

The purpose of the structure is not clear and has given rise to much discussion. Dittmar (1872, pp. 8–9) doubtfully compared it with the 'shoe-lifter' process of *Dicamara* and *Merista*, with the external shell material in its area absent, and Schmidt (1931, pp. 280–1) discussed this theory. The latter author suggested that the notch region was occupied by threads of living material forming a means of attachment similar to a byssus. This, however, does not account for the opening to the body chamber at the anterior end of the notch.

Platform. (Fig. 1c). On the interior of the pedicle valve a slightly raised area extending a short distance anterior to the anterior end of the notch, and with a narrow median furrow which may have raised margins, is termed the platform. This raised area is usually slightly wider than the notch.

Shell structure. The shell is coarsely punctate in both valves, and is composed of two layers, the inner one more coarsely punctate than the outer, with the pores reducing in size from interior to exterior (Meek and Worthen 1870, p. 35). Barrois (1882, p. 238), and Paeckelmann (1930, p. 211) described the presence of a dense epidermal layer on the external surface of *I. davidsoni* and *I. germanica* respectively, though Schmidt (1931, p. 281) did not observe such a layer on his specimens of *I. expansa*. The latter author also recorded that the pores may show branching. Scottish specimens of *I. donbassica* show pores which are curved from anterior internally to posterior externally (Plate VI, fig. 3). In other species of the genus, e.g. *I. pachti* (Plate VI, fig. 2), the pores are more or less normal to the external and internal surfaces.

Systematic Palaeontology

Genus: Isogramma Meek and Worthen, 1870

Isogramma donbassica **Aizenverg**

Plate VI, figs. 1, 3; Plate VII, figs. 1–10

Isogramma paeckelmanni donbassica Aizenverg, 1964, pp. 149–51, pl. 1, figs. 7–18, pl. 2, figs. 19–25.

Discussion. Aigner and Heritsch (1931, pp. 313–4) described the species *I. paeckelmanni* from the Lower Carboniferous of Nötsch, Austria, and Aizenverg (1964, pp. 149–51) erected the subspecies *donbassica.* He distinguished the subspecies on the basis of its dimensions, its more transverse shape, and the less distinct and less frequent radial folds. These distinctions are, in the author's opinion, sufficient to raise Aizenverg's subspecies to specific rank.

Material from the Orchard Beds (E_2) of Midlothian here referred to *I. donbassica* enables some additional details of the internal structure of the brachial valve to be given. The myophore appears to vary in its lobation externally, for on some specimens it is trilobed with poorly defined lateral lobes, whilst on other specimens it appears to be monolobate. This variation may be due to the poor development of the lateral lobes and to the poor preservation of the material. The shaft is massive, long, and without buttress plates. The median septum arises immediately anterior to the shaft, rising to a maximum height and then falling anteriorly towards the valve floor at about three-quarters of the valve length. The anterior portion of the median septum may be somewhat swollen, and immediately anterior to it there is a shallow sulcus which becomes wider and shallower towards the anterior margin of the shell. On either side of the septum there are areas with radial furrows extending to the smoother area which borders the anterior and lateral margins of the shell. This smoother area is anterior to the anterior end of the median septum. Two well-defined, raised and thickened lateral ridges radiate at small angles from the hinge line close to the posterior end of the shaft, dying out close to the lateral margins. No clear interarea is present. Some specimens of the brachial valve show a thickening of the shell from posterior to anterior. The junction between the median septum and the shaft is a point of weakness on this valve, and many specimens have the posterior portion of the valve missing. The shell structure differs somewhat from other described species of *Isogramma* in that the pores curve from anterior internally to posterior externally (Plate VI, fig 3). The dimensions and form of the brachial valve are somewhat variable, as noted by Aizenverg (1964, p. 149), and it may be concave, or resupinate, externally.

Pedicle valves are uncommon in Scottish material but are comparable to the figures given by Aizenverg.

Other specimens, from the Lower Limestone Group (P_2) of the Newmilns, Ayrshire, district show slightly less frequent concentric ridges, and the angle between the margins of the shell on either side of the cardinal process is slightly lower. However the differences fall within the range of variation of Scottish specimens from the Upper Limestone Group.

Isogramma germanica Paeckelmann

Plate VI, figs. 10, 11

Chonetes concentrica ?: von Semenow, 1854, pp. 345–6, pl. 5, figs. 1a–d.
Aulacorhynchus concentricus: Dittmar, 1872, pp. 11–2, pl. 1, figs. 17–20.
Isogramma germanica Paeckelmann, 1930, pp. 211–3, pl. 15, figs. 1–4, non fig. 5.

Discussion. Von Semenow (1854, p. 345–6) described and figured specimens of *Isogramma* as *Chonetes concentrica*? de Koninck but suggested that his specimens belonged to an unknown brachiopod genus. Dittmar (1872, pp. 11–2) redescribed these specimens as *Aulacorhynchus concentricus* von Semenow, and Paeckelmann used some of von Semenow's specimens in his description of *I. germanica*.

A search was made for the type specimens of the species and some of von Semenow's specimens were borrowed from the Humboldt University, Berlin. These included specimens used by Paeckelmann in his description of the species. Paeckelmann's specimens from the Geologisches Landesmuseum, Berlin, have not been traced as yet and therefore von Semenow's material constitutes the available syntypes. Two of these specimens are here figured (Plate VI, figs. 10, 11) to indicate the variability of form within the species.

The specimen figured by Paeckelmann (1930, pl. 15, fig. 5) was included in *I. paeckelmanni* by Aigner and Heritsch (1931, p. 313).

Specimens here determined as *I.* cf. *germanica* (Plate VI, figs. 8, 9) came from Cliff Quarry near Compton Martin, where C. B. Salter collected them from the Hotwells Limestone, D_2 (Green and Welch 1965, p. 27, footnote). These specimens are somewhat variable, but show a smaller number of ridges in the same length than the German form. Smaller specimens are comparable in shape to *I. germanica*, but the larger specimens become longer in relation to width, with increase in size, and the spacing between the ridges becomes greater. The internal details of British specimens are unknown.

Isogramma pachti (Dittmar)

Plate VI, figs. 2, 4; Plate V, figs. 1–6

Aulacorhynchus pachti Dittmar, 1872, pp. 2–6, pl. 1, figs. 1–13.

Discussion. An unsuccessful search has been made for the type specimens of this species. The figures given by Dittmar (1872, pl. 1, figs. 1–13) are sufficient to indicate the characters of the species, although Dittmar (1872, p. 3) noted that they were drawn incorrectly with too few lines of ornament. Cooper (1952, p. 117) questioned the position of the muscle scars shown in Dittmar's fig. 3 (p. 70).

In Scottish specimens referred to the species, the brachial valve interior shows some variation between individuals, but normally the short shaft is supported by buttress plates lying on either side of the median septum and fusing with it at the valve floor. The median septum extends to about three-quarters of the valve length, and anterior to it there is a shallow sulcus which reaches the anterior margin. A slightly raised band, with an ill-defined inner margin parallel to the outer margin of the valve, lies anterior to the anterior end of the median septum. This band extends round the anterior and lateral portions of the valve. Faint radial sulci are present on the inner surface of some specimens.

In the pedicle valve the platform has ill-defined lateral margins, but the median furrow is well developed, expanding slightly anteriorly. There is a poorly defined interarea on the pedicle valve, and a less well-developed one on the brachial valve.

The external ornament of concentric ridges is very fine. Dittmar (1872, p. 3) quoted about 40 in 1 cm, and noted that his figures were drawn incorrectly with too few lines of ornament. Scottish examples exhibit some variation, with possibly rather more ridges in one centimetre than the type specimen. Sarycheva and Sokolskaja (1952, p. 60) quoted figures of 4–5 ridges in 1 mm for this species and Scottish specimens show a similar range.

The Scottish material occurs at two horizons, the Castlecary Limestone at the top of the Upper Limestone Group (E_2) and in No. 3 Marine Band Group, Passage Group (R_1) in a limited area in West Fife. In Northern Ireland specimens determined as *I.* cf. *pachti* by Sir James Stubblefield occurred at 1080 ft in Brackaville No. 1 Bore (1959) in beds regarded as E_2 in age (Fowler *in* Fowler and Robbie 1961, p. 83).

I. carinthiaca has a rather similar outline to *I. pachti*, but is larger, has a less distinct notch, and has fewer ridges, about 14 compared with 20 in 5 mm near the anterior margin. A photograph of the type specimens has been kindly supplied by Dr. Flügel of Graz University and they are here reproduced for comparison (Plate V, figs. 14, 16).

Isogramma salteri sp. nov.

Plate V, figs. 7–13, 15

Diagnosis. Isogramma about 14 mm wide, 9 mm long and 3·6 mm thick. Shell plano- or slightly concavo-convex, markedly convex medianly, falling evenly to the cardinal extremities, greatest width just anterior to the hinge line. No interarea present on either valve. Valves with marked concentric ornament, 6–8 in 1 mm in early stages, 2–4 in anterior half of shell. Both intercalations and bifurcations present. Notch extending to about half-way across pedicle valve, margins diverging from the umbo at about 20°.

Type Specimens

Holotype, GSL Zo 1525, pedicle valve, from Cliff Quarry, 450 yd W.27°S. of Compton Martin church, Somerset, [ST 541 568], Hotwells Limestone (D_2). Dimensions, width 18·3 mm, length 11·8 mm, height 6 mm.

Paratypes, GSL Zo 1522, pedicle valve, same locality and horizon. Dimensions, width 15·2 mm, length 10 mm, height 5·2 mm.

GSL Zo 1497, brachial valve, same locality and horizon. Dimensions, width 14·8 mm, length 8 mm.

GSL Zo 1510, both valves, same locality and horizon. Dimensions, width 10·9 mm, length 7·5 mm, height 3·4 mm.

All the specimens are in the C. B. Salter collection housed in the Institute of Geological Sciences, Leeds.

Description

External characters. The valves are plano- or slightly concavo-convex and the outline of the brachial valve is essentially delta-shaped. The pedicle valve umbo projects beyond the hinge line both in the plane of the commissure and at right angles to it. The hinge line is not straight, and the cardinal extremities are rounded. The greatest width of the valve is slightly anterior to the hinge line. The average ratio width/length of valve measured over the curvature is 1·1 and the range is from 0·88 to 1·41. The range of size observed is width 5·2–24 mm; length (with commissure horizontal) 3·3–12·8 mm, (measured over the curvature) 4·2–21·3 mm. There are no recognizable interareas on either valve. The valves are ornamented with fine irregularly concentric ridges which show intercalations and occasional bifurcations. In the umbonal region both valves are nearly smooth, between the umbo and about 5 mm on the curve there may be between 6 and 8 ridges in 1 mm falling to between 2 and 4 in 1 mm in the anterior portions of the valve, most specimens having 3 in 1 mm near the anterior margin. The length of the notch is variable but in most specimens it is slightly less than half the length of the valve, measured on the curve. The angle contained between the margins of the notch is about 20° but varies between 17° and 23°.

Internal characters. Pedicle valve.—The platform is rather wider than the notch, with indistinct lateral margins. There is no median septum, but a faint median groove with raised margins is developed in the anterior half of the platform. This structure is less well developed anteriorly. The anterior margin of the platform is curved and coincides with the slit between the notch and the platform. The margins of the platform are continued anteriorly as two shallow grooves, and between these lies a faint channel on the mid-line of the valve. Although other markings are present on the interior of the valve the musculature described by Cooper (1952, pp. 116–7) in *I. texanum* has not been recognized.

Brachial valve.—The myophore is monolobate, being formed by a thickening at the posterior margin continuous with well-developed lateral ridges which die out close to the lateral margins of the valve. No shaft is developed, and low buttress plates enclose the posterior extension of the median septum which reaches the valve floor anterior to the pit in the anterior wall of the myophore. The median septum reaches a maximum height at over half-way across the valve and extends to about three-quarters of the length of the valve. A sulcus which becomes wider and less deep near the anterior margin, is developed immediately anterior to the septum. A band, parallel to the anterior and lateral margins of the valve and anterior to the median septum, shows irregular faint radial sulci.

Discussion. I. salteri is one of the smallest of the described species of *Isogramma. I. carinthiaca* is larger, has a less highly convex pedicle valve and possesses a lower number of ridges in one millimetre in the anterior portion of the shell (13–14 compared with 14–18 in *I. salteri*).

So far the species is only known from the original locality where it occurs in some abundance, associated with *I.* cf. *germanica.*

Isogramma scotica sp. nov.

Plate VIII, figs. 1–4

Chonetes concentricus: Davidson, 1863, pp. 278–9, pl. 55, fig. 13.
Aulacorhynchus davidsoni: Davidson, 1884, pp. 283–4.

Diagnosis. Isogramma about 75 mm wide and 36 mm long. Brachial valve flat or slightly concave, transversely elongate, sub-elliptical in outline. Hinge line nearly straight, greatest width at about posterior third of the valve. Ornament of well-defined concentric ridges, about 10–14 in 5 mm in early stages, 6–8 in 5 mm in anterior half of shell. Fine slightly irregular fila may be present in the intervalleys on well-preserved specimens. Pedicle valve not well known.

Type Specimens

Holotype, GSM 93080, brachial valve, from Clattering Well Quarry, 1490 yd E.5°N. of Balnethill, Fife, Charlestown Main Limestone (P_2). Dimensions, width 63 mm, length 29·8 mm.

Paratype, GSE 12750, brachial valve, same locality and horizon. Dimensions, width 78·5 mm, length 38·2 mm.

Holotype housed in Institute of Geological Sciences, Leeds, paratype housed in Institute of Geological Sciences, Edinburgh.

Description

External characters. The brachial valve is flat or slightly concave, the greatest curvature being close to the hinge line. Its outline is transversely elongate, sub-elliptical, with the greatest width at about one-third of the way across the shell. The hinge line is not straight, but nearly so; and the cardinal extremities are well rounded. The range of size observed is width 7–91·5 mm and length 3·8–46 mm. The ornament consists of well-defined concentric ridges, with, on some specimens, fine concentric fila in the intervalleys. The umbonal region is smooth, or nearly so. Between 5 and 10 mm from the umbo there are between 10 and 14 ridges and these figures are reduced to between 6 and 8 ridges in 5 mm in the anterior portions of the valve. The pedicle valve is not well known, but the notch extends to a little over half-way across the valve, and its margins diverge at about 17° on the one specimen available. The notch margins also appear to be rather ill defined, and there appears to be a median furrow as in other species of the genus.

Internal characters. Brachial valve.—No specimens with shell material attached have been seen, although moulds of the internal surface show some details. The cardinal process has a long shaft, but evidence of buttress plates is inconclusive. The median septum is long, extending to about two-thirds of the valve length. A slight flexure of the concentric ornament anterior to the septum suggests that a sulcus may be present in this region of the valve. Faint radial flexures in the anterior portion of the valve are present on one specimen. The lateral ridges extend from close to the myophore to close to the lateral margins, diverging only slightly from the hinge line. Some specimens show a pair of small raised pear-shaped areas lying on either side of the shaft, between it and the lateral ridges.

Discussion. The specimen described by Davidson (1863, pp. 278–9) as *Chonetes concentricus* de Koninck which he later (1884, pp. 283–4) referred to *Aulacorhynchus davidsoni* Barrois is here designated as the holotype of *I. scotica.*

The type specimens of *Aulacorhynchus davidsoni* have not yet been traced. However the dimensions given by Barrois (1882, p. 327) suggest a more rounded form, with a finer ornament than the Scottish specimens. Aizenverg (1964, p. 147) described *I. chernyshevi* from the Lower Carboniferous of Russia, which is rather more semicircular, and smaller than *I. scotica.* The ornament is somewhat similar, although the presence of fine fila in the intervalleys in *I. scotica* is a distinguishing feature, and the frequency of ridges appears to be lower in the Scottish form. Details of the interior of *I. chernyshevi* are not well known, although the median septum in the brachial valve extends beyond half the length of the valve. The pedicle valve of the Russian form is unknown.

British specimens assigned to this species occur at only one locality in Fife; although a form which may be conspecific occurs in the Dinwoodie Beds of the Archerbeck Borehole (see below).

Isogramma sp. A

Plate VII, fig. 13

Description. The brachial valve is flat or nearly so, and the hinge line is almost straight. The valve outline is nearly semicircular, with the greatest width slightly anterior to the hinge. Two specimens show widths of 16 and 20 mm, and lengths of 8 and 10 mm respectively. The ornament consists of concentric ridges with broad intervalleys in which there are fine, rather irregular fila. There are about 9 ridges in 5 mm in the posterior portion of the valve. The trace of the median septum extends to about three-quarters of the length of the valve. The pedicle valve is unknown.

Discussion. The specimens are more markedly semicircular, and are smaller than *I. scotica*, although the shell ornament is similar, with a slightly smaller number of ridges in 5 mm in the posterior portion of the valve.

This form occurs in the Dinwoodie Beds in the Archerbeck Borehole, and in strata correlated with them in Archer Beck, Canonbie. The stratigraphy of these beds was discussed by Wilson (*in* Lumsden and others 1967, pp. 122–3) who concluded that they are of D_1 age. This occurrence of *Isogramma* is thus the earliest recorded in the Carboniferous of Great Britain.

Isogramma sp. B

Plate VII, figs. 11, 12

Description. The brachial valve is small, almost semicircular, with the greatest width just anterior to the hinge. The hinge line is nearly straight. The largest specimen observed has the dimensions, width 17 mm, length 11·5 mm. The valve may be flat or concave. The ornament consists of narrow concentric ridges separated by wide intervalleys, but no fila have been observed. There are between 11 and 13 ridges in 5 mm in the posterior portion of the valve and 6 or 7 in the same distance in the anterior portion. The trace of the cardinal process suggests that the shaft is long, and the median septum extends over half-way across the valve. The pedicle valve is unknown.

Discussion. This form is less markedly semicircular than *I. sp.* A and the ornament is different. Although the number of ridges in 5 mm is similar to that in the posterior portions of *I. scotica*, the number falls more rapidly than in the latter species, and there are no fila present on this form. It is also smaller than *I. scotica*.

Specimens referred to this form are found in the Polquhirter Burn, New Cumnock, Ayrshire, in beds assigned to the Upper Limestone Group. A similar form also occurs in the Muck Water, Dalmellington, associated with *I. donbassica*? in rocks thought to be of Upper Carboniferous age.

Isogramma sp. C

Plate VI, fig. 7

Description. The valves are markedly elongate–oval, with the greatest width slightly anterior to the hinge. The dimensions of the pedicle valve, which is incomplete, are width 23·4 mm, length 10·2 mm (the estimated width being about 26 mm). The brachial valve dimensions are width 22·5 mm, length 9·8 mm. The hinge line of the brachial valve is nearly straight. The ornament consists of regular concentric ridges, about as wide as the intervalleys between them, numbering about 15 in 5 mm on the pedicle valve, and a similar number on the anterior portion of the brachial valve. The notch extends to over halfway across the valve, measured on the curve, and its margins diverge at about 20°. The cardinal process on the brachial valve is poorly preserved, but appears to have a short shaft and long buttress plates which enclose the median septum. The latter extends to about three-quarters of the length of the valve.

Discussion. This form is unlike any other *Isogramma* species recorded from Great Britain, and is not closely comparable to any of the previously described species. It is similar in outline to *I. millepunctata* but is considerably smaller, and would appear to have been more highly inrolled. The frequency of concentric ridges is similar and the angle between the margins of the notch is at the lower end of the range quoted by Dunbar and Condra (1932, p. 283) for *I. millepunctata*. However the latter species has not so far been recorded from the Lower Carboniferous, whereas this form occurs in the Lower Limestone Group (P_2) in the Huggin Craig Burn, Newmilns, Ayrshire.

Stratigraphical Distribution

In England *I.* cf. *germanica* and *I. salteri* are the only species recorded, both occurring in the Lower Carboniferous, and no isogrammids have so far been recorded from the Upper Carboniferous. In Ireland only *I.* cf. *pachti* has been recorded, from the Namurian. In Scotland, however, a number of species occur; *I. donbassica* in Viséan and Namurian strata, *I. scotica* from the Viséan and *I. pachti* from the Namurian, together with a number of other forms from Viséan and Namurian strata.

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Explanation of Plate V

Depositories of specimens: GSE, Institute of Geological Sciences, Edinburgh; UGP, Graz University; GSL Zo, Institute of Geological Sciences, Leeds.

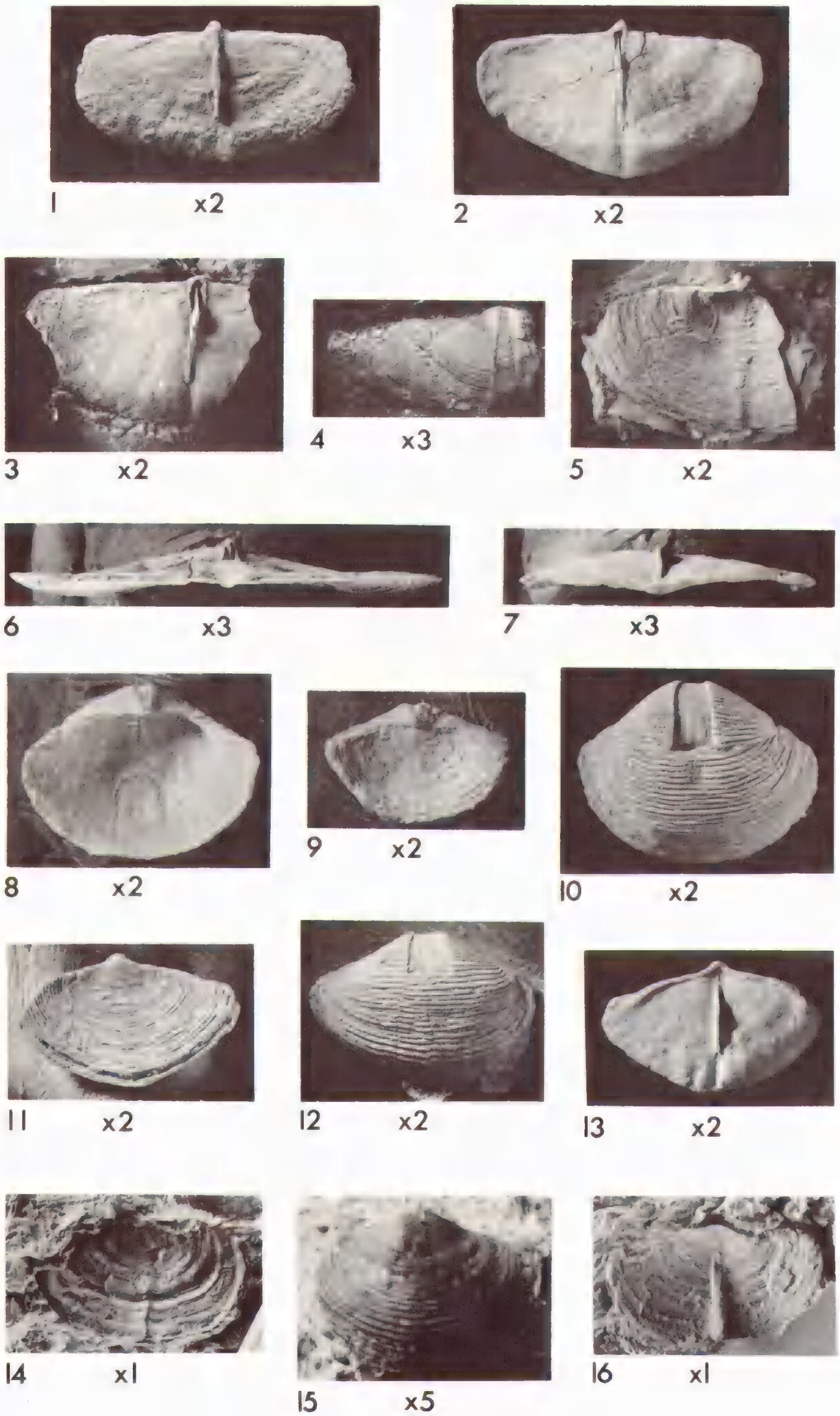
Figs. 1–6. *Isogramma pachti* (Dittmar); **1** x 2, GSE 12745, brachial valve interior, Blinkeerie Farm Bore, Fife, No. 3 Marine Band Group, Passage Group (R_1). **2** x 2, GSE 12748, brachial valve interior, as fig. 1. **3** x 2, GSE 12746, brachial valve interior, as fig. 1. **4** x 3, GSE 12117, incomplete pedicle valve exterior, Solsgirth No. 1 Bore, Fife, Castlecary Limestone, Upper Limestone Group (E_2). **5** x 2, GSE 12747, incomplete brachial valve exterior, as fig. 1. **6** x 3, GSE 12748, external face of cardinal process of brachial valve, as fig. 1, (p. 72).

Figs. 7–13. *Isogramma salteri* sp. nov.; **7** x 3, GSL Zo 1497, external face of cardinal process of brachial valve, Cliff Quarry, 450 yd W.27°S. of Compton Martin church, Somerset, Hotwells Limestone (D_2). **8** x 2, GSL Zo 1525, Holotype, pedicle valve interior, as fig. 7. **9** x 2, GSL Zo 1510, Paratype, brachial valve exterior with umbo of pedicle valve overlapping the valve, as fig. 7. **10** x 2, GSL Zo 1525, pedicle valve exterior, as fig. 7. **11** x 2, GSL Zo 1497, Paratype, brachial valve exterior, as fig. 7. **12** x 2, GSL Zo 1522, Paratype, pedicle valve exterior, as fig. 7. **13** x 2, GSL Zo 1497, brachial valve interior, as fig. 7, (p. 73).

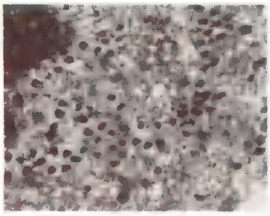
Fig. 14. *Isogramma carinthiaca* Aigner x 1, UGP 736, Syntype, Nötsch, Austria, Lower Carboniferous. Figured by Aigner (1931, pl. 1, fig. 10), (p. 73).

Fig. 15. *Isogramma salteri* sp. nov. x 5, GSL Zo 1498, juvenile pedicle valve, showing position of margins of notch anterior to the notch itself, as fig. 7.

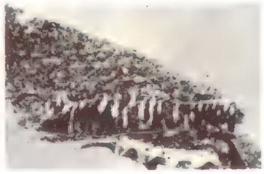
Fig. 16. *Isogramma carinthiaca* Aigner x 1, UGP 736, Syntype, as fig. 14. Figured by Aigner (1931, pl. 1, fig. 9).



CARBONIFEROUS *ISOGRAMMA*

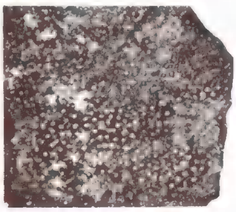


1 ×13

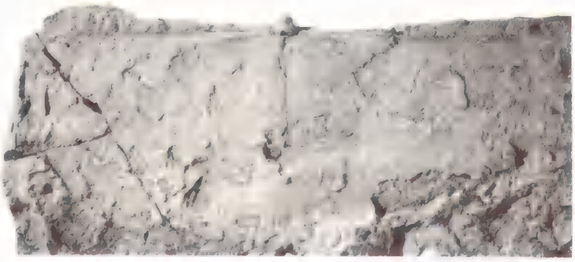


2 ×13

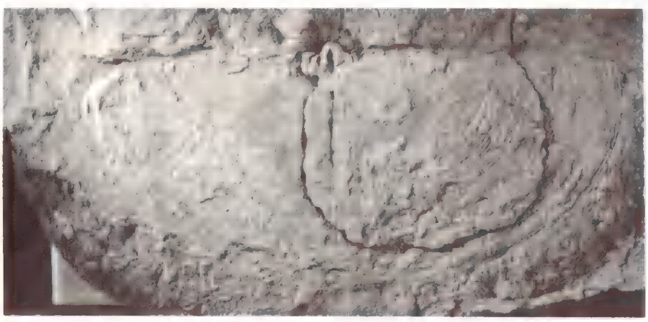
3 ×13



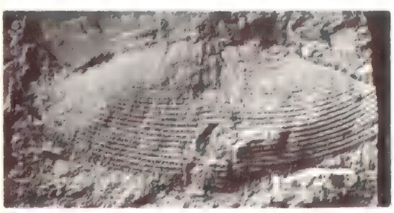
4 ×13



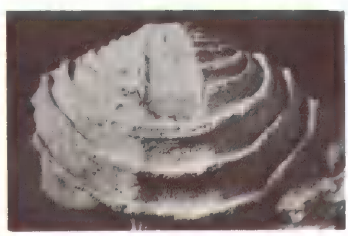
5 ×1



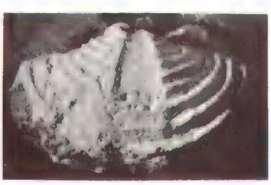
6 ×1



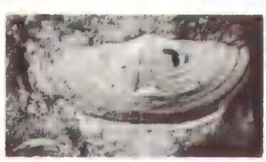
7 ×2



8 ×2



9 ×2



10 ×1

11 ×1

CARBONIFEROUS *ISOGRAMMA*

Explanation of Plate VI

Depositories of specimens: GSE, PS, Institute of Geological Sciences, Edinburgh; MB, Paläontologische Museum, Humboldt Universität, Berlin; X, Department of Geology, University of Illinois; GSL Zo, Institute of Geological Sciences, Leeds.

Fig. 1. *Isogramma donbassica* Aizenverg x 13, PS 3122, tangential section of brachial valve, showing pores infilled by dark material, small tributary of River North Esk, 240 yd E.36°N. of Auchencorth, Midlothian, Orchard Beds, Upper Limestone Group (E_2), (p. 71).

Fig. 2. *Isogramma pachti* (Dittmar) x 13, PS 3124, transverse section of pedicle valve, showing pores, Solsgirth No. 1 Bore, Fife, Castlecary Limestone, Upper Limestone Group (E_2), (p. 72).

Fig. 3. *Isogramma donbassica* Aizenverg x 13, PS 3121, transverse section of brachial valve, showing pores infilled with dark material, as fig. 1.

Fig. 4. *Isogramma pachti* (Dittmar) x 13, PS 3123, tangential section of brachial valve, showing pores, as fig. 2.

Figs. 5, 6. *Isogramma millepunctata* (Meek and Worthen); **5** x 1, X 280, Syntype, brachial valve interior, Marion County, Illinois, U.S.A., Upper Carboniferous. Figured as *Chonetes ?? millepunctata* by Meek and Worthen (1873, pl. 25, fig. 3a). **6** x 1, X 280, Syntype, brachial valve interior, as fig. 5. Figured as *Chonetes ?? millepunctata* by Meek and Worthen (1873, pl. 25, fig. 3b), (p. 68).

Fig. 7. *Isogramma sp.* C x 2, GSE 12751, pedicle valve exterior, Huggin Craig Burn, 330 yd E.11°N. of Clearmount, Newmilns, Ayrshire, Lower Limestone Group (P_2), (p. 77).

Figs. 8, 9. *Isogramma* cf. *germanica* Paeckelmann; **8** x 2, GSL Zo 1528, pedicle valve exterior, Cliff Quarry, 450 yd W.27°S. of Compton Martin church, Somerset, Hotwells Limestone (D_2). **9** x 2, GSL Zo 1526, pedicle valve exterior, as fig. 8, (p. 72).

Figs. 10, 11. *Isogramma germanica* Paeckelmann; **10** x 1, MB.B. 117.2, Syntype, mould of pedicle valve interior, Hausdorf, Germany, Lower Carboniferous. Figured as *Chonetes concentrica?* by von Semenow (1854, pl. 5, fig. 1c). **11** x 1, MB.B. 117.1a, Syntype, mould of pedicle valve interior, as fig. 10. Figured as *Chonetes concentrica?* by von Semenow (1854, pl. 5, fig. 1a), and cited by Paeckelmann (1930, p. 213) as specimen 10a, (p. 72).

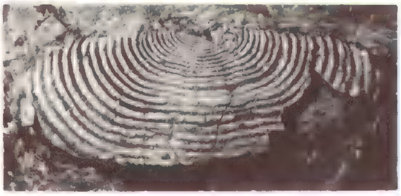
Explanation of Plate VII

All specimens are housed in the Institute of Geological Sciences, Edinburgh.

Figs. 1–10. *Isogramma donbassica* Aizenverg; **1** x 1, GSE 12736, brachial valve exterior, small tributary of River North Esk, 240 yd E.36°N. of Auchencorth, Midlothian, Orchard Beds, Upper Limestone Group (E_2). **2** x 1, GSE 12737, brachial valve exterior, as fig. 1. **3** x 1, GSE 12740, incomplete pedicle valve exterior, as fig. 1. **4** x 2, GSE 12738, incomplete brachial valve exterior showing external face of cardinal process, as fig. 1. **5** x 1, GSE 12741, mould of brachial valve exterior, Gore Water, 350 yd N.W. of Shank Bridge, Midlothian, Orchard Beds, Upper Limestone Group (E_2). **6** x 3, GSE 12739, incomplete brachial valve exterior showing external face of cardinal process, as fig. 1. **7** x 1 GSE 12744, mould of brachial valve exterior, Huggin Craig Burn, 330 yd E.11°N. of Clearmount, Newmilns, Ayrshire, Lower Limestone Group (P_2). **8** x 1, GSE 12743, latex impression of mould of brachial valve exterior, as fig. 7. **9** x 1, GSE 12735, brachial valve interior, as fig. 1. **10** x 1, GSE 12742, incomplete mould of pedicle valve interior, as fig. 7, (p. 71).

Figs. 11, 12. *Isogramma sp.* B; **11** x 2, GSE 12753, mould of brachial valve exterior, Polquhirter Burn, 150 yd S.4°W. of High Polquhirter, New Cumnock, Ayrshire, Upper Limestone Group (E_2). **12** x 2, GSE 12752, incomplete mould of brachial valve exterior, as fig. 11, (p. 76).

Fig. 13. *Isogramma sp.* A x 1, GSE 12271, mould of brachial valve exterior, Archerbeck Bore, Canonbie, Dumfriesshire, Dinwoodie Beds (D_1), (p. 76).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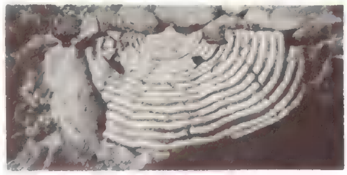
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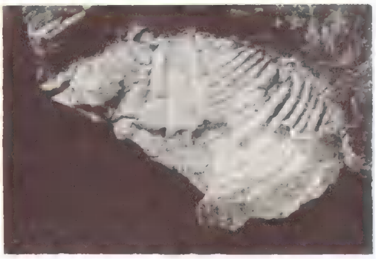
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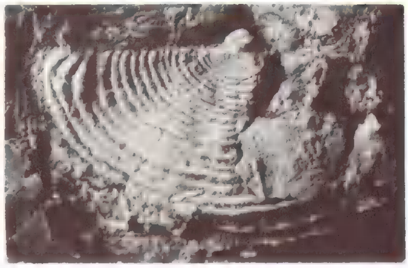
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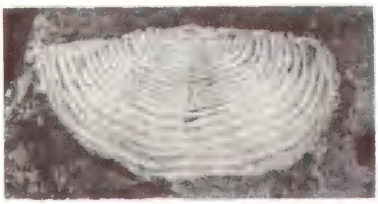
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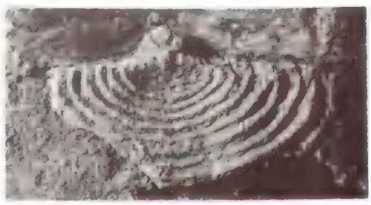
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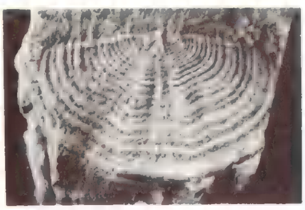
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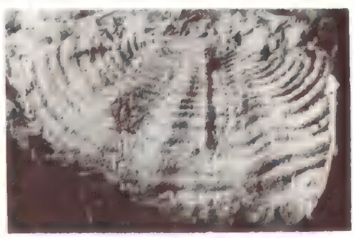
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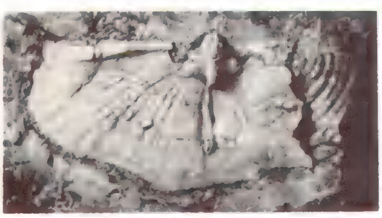
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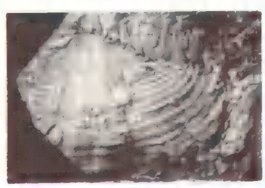
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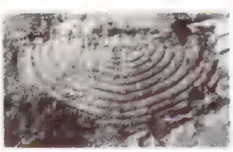
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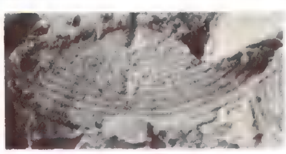
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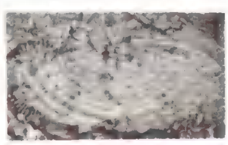
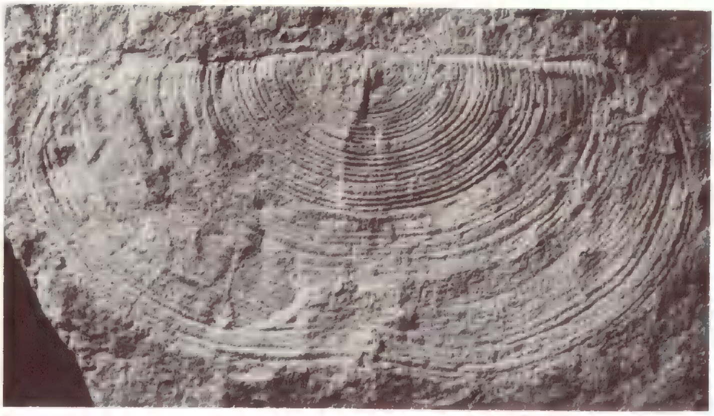

13 ×1

CARBONIFEROUS *ISOGRAMMA*



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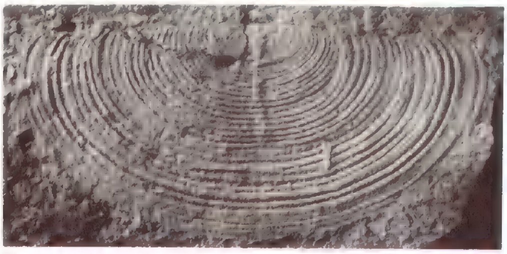

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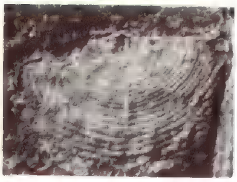

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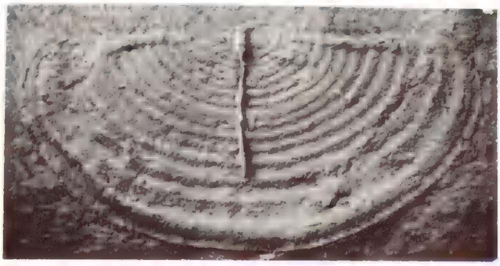

5 ×2

CARBONIFEROUS *ISOGRAMMA*

Explanation of Plate VIII

Depositories of specimens: GSE, Institute of Geological Sciences, Edinburgh; GSM, Institute of Geological Sciences, Leeds; other specimens in the collection of Dr. A. Wattison, Anstruther.

Figs. 1–4. *Isogramma scotica* sp. nov.; **1** x 1, GSE 12750, Paratype, mould of brachial valve exterior, Clattering Well Quarry, 1490 yd E.5°N. of Balnethill, Kinnesswood, Fife, Charlestown Main Limestone, Lower Limestone Group (P_2). **2** x 1, incomplete mould of pedicle valve interior, with part of mould of brachial valve exterior, as fig. 1. **3** x 1, GSM 93080, Holotype, mould of brachial valve exterior, as fig. 1. Figured as *Chonetes concentricus?* by Davidson (1863, pl. 55, fig. 13). **4** x 5, incomplete mould of juvenile brachial valve exterior, as fig. 1, (p. 75).

Fig. 5. *Isogramma* cf. *scotica* x 2, GSE 12429, latex impression of mould of brachial valve exterior, showing traces of internal structures, as fig. 1.

V.—A PETROGRAPHICAL REVIEW OF SOME THIN SECTIONS OF STONE AXES

BY

H. A. Hope Sanderson, M.Sc.

Text-figures 1–5

Summary. The paper summarizes the petrological groups of stone axes already established, and lists are given of thin sections of axes in the collections of the Institute of Geological Sciences. Descriptions are given of some rock types from which stone axes found in Britain were made, but which have not previously been assigned to groups.

Introduction

In 1936 the South-Western Group of Museums appointed a sub-committee under the chairmanship of the late Mr. A. Keiller, which included Dr. F. S. Wallis as petrologist, to study the petrological identification of stone implements. It was decided to classify the stone axes in a number of groups, each with definite characteristics. The provenance of the rock was given where known. Nine groups were described in 1941 (Keiller and others 1941, p. 50). In 1949 the survey was put on a national basis with the creation of an Implement Petrology Sub-Committee (Convenor: Professor W. F. Grimes) under the aegis of the Council for British Archaeology. The cost of the technical work has where necessary been defrayed by a grant from the Leverhulme Trust. More groups have been added by the South-Western Committee and by others as the use of different rock types for stone axes has been discovered. The thin sections of stone axes accumulated in the Institute collections through the years are reviewed in the present paper. It has been possible to assign many to the 21 groups already established.

In this review a more detailed description of the rock types of some groups is given and examples of thin sections of stone axes in the Institute collections are listed for each group. Specimens have not been assigned to groups IA, IIA, IIIA, IVA, X and XI, as material for matching was not available. A selected bibliography is given for each group. Thin sections of stone axes that do not belong to any of the 21 groups so far established, but whose source rocks have probably been traced, are also described. Several thin sections of stone axes whose provenance is unknown have not been included in this review.

It is interesting to note that early man discovered some of the hardest rocks in the country for making his implements. Often these rocks occurred in very small outcrops, for example, the porcellanite from Tievebulliagh and Rathlin Island, and the riebeckite-felsite from the Shetland Islands. Flint implements have not been included in this review but were very commonly used.

The writer would like to thank Professor W. F. Grimes for donating thin sections of typical rocks of many of the groups, Professor F. W. Shotton, F.R.S., for the loan of thin sections and Dr. P. A. Sabine for reading the manuscript.

Group I (Fig. 1)

A thin section of a stone axe typical of this group shows the rock to be a medium-grained epidiorite (ENQ 1980). It contains crystals of colourless to

FIG. 1. *Distribution of Stone Axes from Groups I to II*

pale pinkish brown augite altered round the edges to green fibrous amphibole. Crystals of twinned albite-oligoclase are very altered to sericite and are crowded with flakes of amphibole and some biotite. Large irregular crystals of iron ore and grains of sphene also occur.

This rock has been compared by Wallis (*in* Stone and Wallis 1951) with specimens from the Mount's Bay area, Cornwall, but those in the Institute collection do not match. The present writer has found that epidiorites from Cox Tor, near Petertavy, Devon (E 995, E 9435, E 13696)[1] and from Trevassick, St. Austell, Cornwall (E 4023) have affinities.

Thin sections of stone axes in the Institute collection matching or very similar to the typical specimen of Group I are listed below:

ENQ 78, Charford, near Downton, Wiltshire; ENQ 80, East Harnham, Wiltshire; ENQ 914, Hambledon, Surrey; ENQ 932, Midhurst, Sussex; ENQ 1099, Keston, Kent; ENQ 1207, Blewburton, Aston Upthorpe, Berkshire; ENQ 1254, Freckenham, Suffolk; ENQ 1332, Cassiobury Park, Watford, Hertfordshire; ENQ 1434, Lakenheath, Suffolk; ENQ 1437, Ickleton, Cambridgeshire; ENQ 1438, near Soham, Cambridgeshire; ENQ 1439, Wretton, Norfolk; ENQ 1447, Barton Bendish, Norfolk; ENQ 1511, Loundrun, Suffolk; ENQ 1517, Burgh-by-Woodbridge, Suffolk; ENQ 1519, Martlesham, Suffolk; ENQ 1523, Ampthill, Bedfordshire; ENQ 1588, Bradfield, Berkshire; ENQ 1590, Sutton Courtenay, Berkshire; ENQ 1593, Wokingham, Berkshire; ENQ 1596, Wallingford, Berkshire; ENQ 1602, River Thames, Tilehurst, Berkshire; ENQ 1605, Monkey Island, Bray, Thames, Berkshire; ENQ 1609, Coveney Fen, Cambridgeshire; ENQ 1611, South Church Waters, Essex; ENQ 1612, Dover

[1]Numbers preceded by E, ENQ, S, NI, refer to sliced rocks in the Institute of Geological Sciences collection.

Court, Essex; ENQ 1613, Walton-on-Naze, Essex; ENQ 1614, near Barking, Essex; ENQ 1615–17, Walton-on-Naze, Essex; ENQ 1620, Walton-on-Naze, Essex; ENQ 1626, Ewelme Downs, Oxfordshire; ENQ 1725, River Thames, Maidenhead, Berkshire; ENQ 1730, 1732, Burwell, Cambridgeshire; ENQ 1733, Huntingdon Road, Cambridgeshire; ENQ 1735, near Cambridge; ENQ 1736, Reach, Cambridgeshire; ENQ 1745, Swaffham, Cambridgeshire; ENQ 1747, Conington, Huntingdonshire; ENQ 1863, Layer Breton, Essex; ENQ 1878, Lakenheath, Suffolk; ENQ 1996, Cambridge Fens, Cambridgeshire; ENQ 2005, Pondfields Farm, Colchester, Essex; ENQ 2018, Hockwold cum Wilton, Norfolk; ENQ 2021, Tuddenham East, Norfolk.

Selected Bibliography. Evens and others 1962, p. 211; Keiller and others 1941, p. 51; Stone and Wallis 1947, p. 48; 1951, p. 101; Wallis 1955, p. 148.

Group I A

This group is stated by Wallis to be very similar to Group I. He describes the augite as not being quite as altered and the feldspars not so extensively riddled with small needles of hornblende.

Selected Bibliography. Evens and others 1962, p. 213; Stone and Wallis 1951, p. 105.

Group II (Fig. 1)

A fine-grained epidiorite from between Lay Point and St. Ives, Cornwall (E 921) has been matched by Wallis (*in* Keiller and others 1941) with a stone axe typical of this group. The rock contains plates and fibres of pale green amphibole which has completely replaced the original pyroxene. Patches of biotite and grains of iron ore also occur. The feldspar has been very altered to sericite.

Examples in the Institute collection are: ENQ 1510, Sutton, Suffolk; ENQ 1867, Ardleigh, Essex.

Selected Bibliography. Evens and others 1962, p. 214; Keiller and others 1941, p. 55; Stone and Wallis 1951, p. 106; Wallis 1955, p. 149.

Group II A

The rock is very similar to that of Group II but Wallis (*in* Stone and Wallis 1951) mentions the presence of a little apatite and the feldspar base as being clear and unweathered.

Selected Bibliography. Evens and others 1962, p. 214; Stone and Wallis 1951, p. 106.

Group III

The rock is an epidiorite (E 32292) containing large plates of green fibrous hornblende and laths of sericitized oligoclase-andesine. Scattered crystals of iron ore and needles of apatite also occur.

The locality for this rock is a quarry near Trenow, between Perranuthnoe and Marazion, Cornwall. Stone axes have been matched with the rock by Wallis (*in* Keiller and others 1941) but there are no examples of this group in the Institute collection.

Selected Bibliography. Evens and others 1962, p. 214; Keiller and others 1941, p. 55; Stone and Wallis 1947, p. 49; 1951, p. 109; Wallis 1955, p. 149.

Group III A

This rock was described by Wallis (*in* Stone and Wallis 1951) as being similar in texture to that of Group III but the hornblende is generally in fan-shaped sheaves, and brown mica and epidote are commonly present.

Selected Bibliography. Evens and others 1962, p. 215; Stone and Wallis 1951, p. 110.

Group IV (Fig. 2)

The rock is an amphibolite (ENQ 1113) containing plates, needles and blades of amphibole, some colourless and some pleochroic in pale brown and green. Also present are patches of chlorite and serpentinous material, some of which are possibly replacing olivine crystals, the cracks being filled with iron ore.

The rock is similar to a specimen (E 9356) from Balstone Down, Callington, Cornwall, which is the locality suggested by Wallis (*in* Stone and Wallis 1951) for this group of stone axes. Examples in the Institute collection: ENQ 1113, Newton Abbot, Devon; ENQ 1258, Hazard Hill, Totnes, Devon; ENQ 1321, The Thames, Victoria Bridge, Windsor, Berkshire; ENQ 1610, Great Oakley, Essex.

Selected Bibliography. Evens and others 1962, p. 215; Keiller and others 1941, p. 56; Stone and Wallis 1947, p. 49; 1951, p. 113; Wallis 1955, p. 149.

Group IV A

This group is described by Wallis (*in* Stone and Wallis 1947) as similar to Group IV but the hornblende is in separated small needles rather than bundles or sheaves, and granular epidote is also present.

Selected Bibliography. Evens and others 1962, p. 215; Stone and Wallis, 1947, p. 50; 1951, p. 113.

Group V

This is not an important group as only two implements have been assigned to it. The thin sections of these are not in the Institute collection, but one of them, (No. 179) has been examined by Dr. J. Phemister (*in* Keiller and others 1941). He described the rock in the original report as "a calc-silicate hornfels composed essentially of very small prisms of amphibole and small plates of lime scapolite. Granules of sphene are abundant." The present writer has also seen the thin section and records crystals of cordierite.

The rock has been compared by Wallis (*in* Stone and Wallis 1951) with a specimen from Hellesveor Cliff, about 300 yd east of Hor Point, near St. Ives, Cornwall.

Selected Bibliography. Evens and others 1962, p. 216; Keiller and others 1941, p. 56; Stone and Wallis 1951, p. 114.

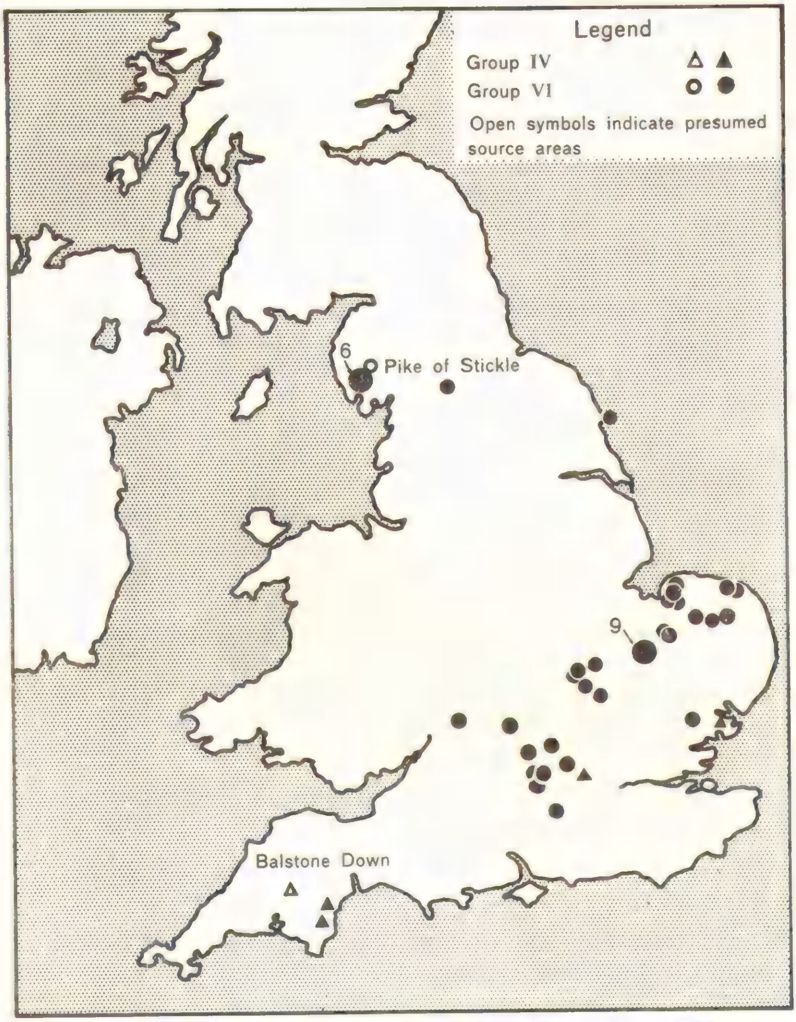

FIG. 2. *Distribution of Stone Axes from Groups IV and VI*

Group VI (Fig. 2)

The stone axe factory for this group was located by Professor D. M. S. Watson (*see* Keiller and others, 1941) at Pike of Stickle, Westmorland. The rock is a medium-grained crystal-vitric tuff (E 22773) containing tiny fragments of quartz and feldspar, small crystals of iron ore, and aggregates of flakes of epidote, in a very fine-grained matrix of micro-felsitic material, patches of glass, and granular sphene.

Numerous stone axes have been discovered which belong to this group. Some of the rocks are banded tuffs. A very fine-grained tuff (E 22774) from Pike of Stickle, which is similar in other respects, has also been used for axes.

Thin sections of stone axes belonging to this group in the collection are listed below:

ENQ 40, Andoversford, Gloucestershire; ENQ 425, Parish of Muker, Swaledale, Yorkshire; ENQ 580, Frensham, Surrey; ENQ 873, Minster Lovell, Oxfordshire; ENQ 1005, Mite Valley, Eskdale, Cumberland; ENQ 1006, Wasdale Screes, Westmorland; ENQ 1197, Beacon Hill, Flamborough Head, Yorkshire; ENQ 1209, Whiteleaf, Buckinghamshire; ENQ 1212, Runton, Norfolk; ENQ 1213, Bessingham, Norfolk; ENQ 1264, Hurst Fen, Mildenhall, Suffolk; ENQ 1420, Sharnbrook, Bedfordshire; ENQ 1436, Swaffham, Cambridge; ENQ 1440, Thornham, Norfolk; ENQ 1441, Salhouse, Norfolk; ENQ 1445, Wereham, Norfolk; ENQ 1505, Tulip Hills, Great Dunham, Norfolk; ENQ 1520, Pavenham, Bedfordshire; ENQ 1521, Kempston, Bedfordshire; ENQ 1524, Wyboston, Bedfordshire; ENQ 1586, Sandy, Bedfordshire; ENQ 1592, Grazeley, Berkshire; ENQ 1594, River Thames, Benson, Oxfordshire; ENQ 1600, River Thames, Reading, Berkshire; ENQ 1606, Mapledurham, Berkshire; ENQ 1608, Amerden, Taplow, Buckinghamshire; ENQ 1728, Bottisham, Cambridgeshire; ENQ 1731, 1739, Burwell, Cambridgeshire; ENQ 1740, Isleham, Cambridgeshire; ENQ 1741, Soham, Cambridgeshire; ENQ 1744, Swaffham, Cambridgeshire; ENQ 1751, Snettisham, Norfolk; ENQ 1777–9, Hurst Fen, Mildenhall, Suffolk; ENQ 1874, Thuxton, Norfolk; ENQ 1922–3, Pike of Stickle, Westmorland; ENQ 1981, Thorn Crag, Westmorland; ENQ 1982, Pike of Stickle, Westmorland; ENQ 1995, Bottisham Lode, Cambridgeshire; ENQ 1998, Isle of Ely, Cambridgeshire; ENQ 2007, Mile End, Moore's Farm, Essex; ENQ 2019, Feltwell, Norfolk; ENQ 2020, Great Bireham, Norfolk; ENQ 2024, Babingly, Norfolk; ENQ 2030, Hockwold cum Wilton, Norfolk.

Selected Bibliography. Bunch and Fell, 1949, pp. 1–20; Evens and others 1962, p. 216; Keiller and others 1941, p. 58; Stone and Wallis 1947, p. 51; 1951, p. 115; Wallis 1955, p. 149.

Group VII (Fig. 3)

As early as 1919 Hazzledine Warren discovered stone axes made from rock from Graig Lwyd Quarry, Caernarvonshire. The rock is a porphyritic microdiorite (ENQ 1983) containing angular crystals of a very pale brown augite and bastite pseudomorphs after enstatite. Laths of oligoclase-andesine have been altered to saussurite. These are set in a fine-grained granophyric matrix of quartz and alkali-feldspar. Small laths of oligoclase, patches of chlorite, a few flakes of biotite, small crystals of iron ore and grains of sphene also occur. A similar rock (E 31417) is found nearby at Garreg Fawr Quarry.

Examples in the Institute collection are: ENQ 1340, Charmy Down, near Bath, Somerset; ENQ 1388, Winster, Derbyshire; ENQ 1501, Staplecross, Sussex; ENQ 1737, Swaffham, Cambridgeshire; ENQ 2048, Chertsey, Surrey; E 15623, Nailsworth, Gloucestershire.

South of Garreg Fawr Quarry, at Garreg Fawr crags, a very fine-grained variety of the rock (E 31415–6) occurs. The groundmass has a slightly more andesitic texture than the typical Graig Lwyd rock.

There are two examples in the Institute collection: ENQ 1598, River Thames, Bray Reach, Berkshire (Reading Museum BER 20); ENQ 2032, Mildenhall,

FIG. 3. *Distribution of Stone Axes from Groups VII to VIII*

Suffolk, (Coll. H. C. Frost, Goldhanger, Essex, S 37). This might be established as a sub-group of Group VII.

Selected Bibliography. Evens and others 1962, p. 216; Keiller and others 1941, p. 60; Stone and Wallis 1947, p. 51; 1951, p. 119; Wallis 1955, p. 149.

Group VIII (Fig. 3)

This group is characterized by a fine-grained silicified tuff or rhyolite (ENQ 1110) containing small fragments of quartz and feldspar in a microcrystalline mosaic of quartz and possibly feldspar. Aggregates of small grains of sphene and iron ore also occur.

A locality at Great Langdale, Westmorland, was suggested by Bunch and Fell (1949) for this rock. Mrs. J. E. Morey (1950) made a search of the Institute collection and found that some rocks from south-west Wales matched remarkably well. Specimens from Ramsey Island (E 8900, E 9607, E 9628) and a specimen from Mountjoy, Pembrokeshire (E 5721) are very similar to the thin sections of stone axes of this group in the collection; ENQ 1076, 1110, Paviland Cave, Glamorgan; ENQ 1480, Eastbourne, Sussex; ENQ 1627, Eynsham, Oxfordshire; ENQ 1750, Thurlton, Norfolk.

Selected Bibliography. Bunch and Fell 1949, 1–20; Evens and others 1962, p. 217; Keiller and others 1941, p. 63; Morey 1950, p. 191; Stone and Wallis 1947, p. 51; 1951, p. 122; Wallis 1955, p. 149.

Group IX (Fig. 4)

A porcellanite (NI 320) typical of this group comes from Tievebulliagh, County Antrim. The rock, which has been described by Jope (1953) and Morey

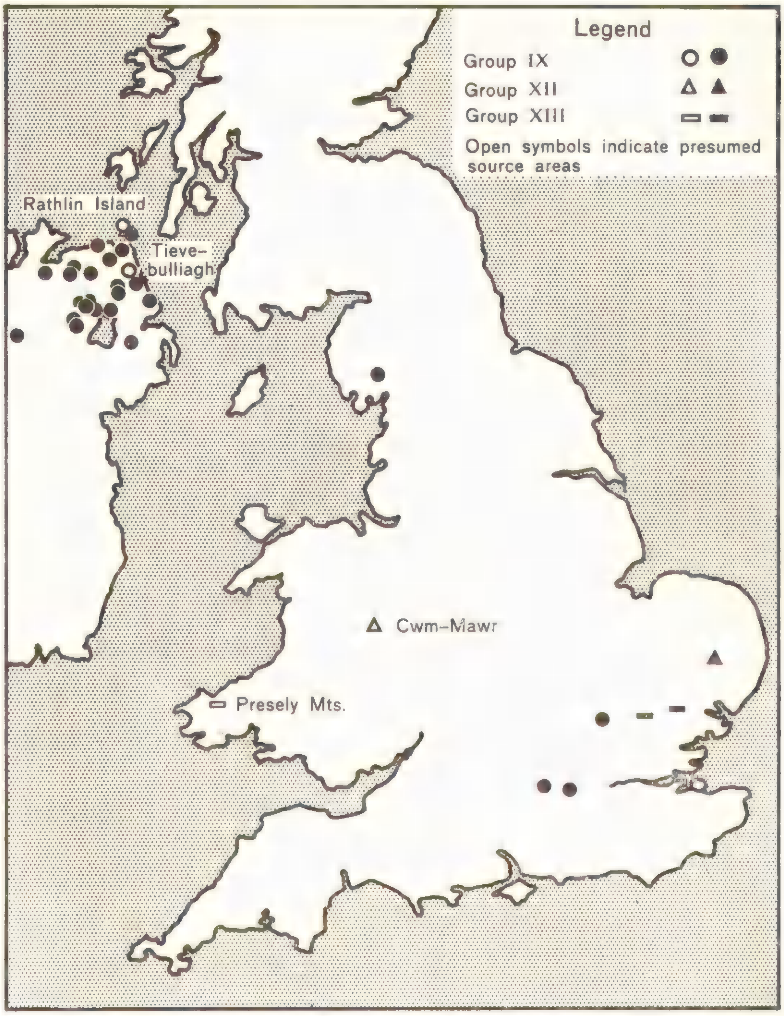

FIG. 4. *Distribution of Stone Axes from Groups IX, XII and XIII*

and Sabine (1953) contains large aggregates of opaque to dark red hematite, in the centres of which are small amounts of colourless, partially isotropic cristobalite. These aggregates are set in a fine-grained groundmass of needles of mullite.

Porcellanites (NI 933–9, 941, 949–57) from Brockley, Rathlin Island, also included in this group, have recently been described by Sabine *in* Wilson and Robbie (1966). They contain mullite but differ from the Tievebulliagh porcellanites by the presence of abundant spinel and some cordierite. Only one specimen contains an appreciable amount of magnetite. The majority of thin sections of the stone axes in the Institute collection belonging to this group are similar to the Tievebulliagh rocks, which would indicate that this was the main factory site. However it is possible that both types of rock occur at Rathlin Island and a more extensive search of the factory area might show this to be the case. Three specimens (NI 913–5) not *in situ*, from the Brockley Factory site are similar to the Tievebulliagh rocks in thin sections. They have been X-rayed by Mr. B. R. Young (films X 3095–3103) and found to contain the minerals typical of the Tievebulliagh material.

Although there are similarities between the Tievebulliagh and Rathlin porcellanites, the rock is very distinctively different from other types and assignment of its provenance to Northern Ireland can generally be stated with considerable confidence. Examples in the Institute collection are: ENQ 1154, Tilborne, Ulster; ENQ 1155, Gortgill, Toome, Antrim; ENQ 1156–60, Trillick, Tyrone; ENQ 1162, Ballycastle, Antrim; ENQ 1163–5, Black Park, Armoy, Antrim; ENQ 1166–7, Barsh Mills, near Portrush, Antrim; ENQ 1168, Garvagh, Co. Derry; ENQ 1169, Lisburn, Antrim; ENQ 1170, Mullaghasauole, near Larne, Antrim; ENQ 1171, near Ballymena, Antrim; ENQ 1199, Ballymena, Antrim; ENQ 1200, Clough, Antrim; ENQ 1201, Toome, Antrim; ENQ 1202, Rathlin Island, Antrim; ENQ 1218, Knockagin, Desertmartin, County Derry; ENQ 1219–20, Killygullig, Tami O'Grilly, County Derry; ENQ 1221, Moyheelan, Ballynascreen, County Derry; ENQ 1222, Mullagheoy, Ballyscullion, County Derry; ENQ 1223, Dunclady, Maghera, County Derry; ENQ 1224, Cabragh, Termoneeny, County Derry; ENQ 1225, Terryddo Clyde, Balteagh, County Derry; ENQ 1226, Dungiven, County Derry; ENQ 1227, Faughanvale, County Derry; ENQ 1228, Carigadick, Maghera, County Derry; ENQ 1229, Crannaghan, Killetach, County Derry; ENQ 1230, Broagh, Termoneeny, County Derry; ENQ 1231, near Cookstown, Tyrone; ENQ 1232, Lissan, Tyrone; ENQ 1319, River Thames, Reading, Berkshire; ENQ 1390, Windermere, Westmorland; ENQ 1595, Binfield, Berkshire; ENQ 1621, Hitchin, Hertfordshire.

Selected Bibliography. Agrell and Langley 1958, p. 93; Evens and others 1962, p. 217; Jope 1953, p. 31; Keiller and others 1941, p. 63; Morey and Sabine 1953, p. 56; Sabine *in* Wilson and Robbie 1966, 242–9; Stone and Wallis 1947, p. 52; 1951, p. 126; Wallis 1955, p. 149.

Group X (originally Group VII A)

A fine-grained dolerite described by Wallis (*in* Stone and Wallis 1951) as containing a ferro-magnesian mineral near an amphibole, and magnetite. The rock has been traced (Evens and others 1962) to Brittany.

Selected Bibliography. Evens and others 1962, p. 218; Stone and Wallis 1951, p. 121.

Group XI

A very fine-grained silicified tuff similar to Group VIII.

Selected Bibliography. Evens and others 1962, p. 218; Stone and Wallis, 1947, p. 52; 1951, p. 126.

Group XII (Fig. 4)

The rock is a picrite (E 19892) traced to Cwm-mawr, Corndon, Shropshire, by Shotton and others (1951). It contains rounded crystals of olivine altered marginally to serpentine and chlorite. Also present are plates of pale brown augite and small laths of labradorite altered to sericite. Irregular crystals of iron ore and a few flakes of biotite also occur.

There is only one example in the Institute collection, from Scole, Norfolk. (ENQ 2016).

Selected Bibliography. Evens and others 1962, p. 219; Shotton and others 1951, p. 159; Stone and Wallis 1951, p. 127; Wallis 1955, p. 150.

Group XIII (Fig. 4)

A spotted dolerite (ENQ 1986) from the Presely Mountains, Pembrokeshire; has been used for stone axes belonging to this group. The rock was first described by H. H. Thomas (1923) when he discovered it was identical with one of the suite of 'bluestones' used by early man for part of the Inner Circle and Horseshoe at Stonehenge. The spots are composed of aggregates of crystals of oligoclase-albite. The rock also contains plates of pale yellow to almost colourless augite and irregular crystals of iron ore. The feldspar is often altered to grains of epidote and patches of chlorite. The matrix is partially silicified.

Examples in the Institute collection are: ENQ 1868, Lamarsh, Essex; ENQ 2009, Thaxted, Essex.

The name 'preselite' has been used in archaeological literature but petrologists generally prefer not to use the name. Miss E. M. Guppy notes concerning the name (personal communication):

> "The term Preselite has been used by archaeologists since 1936 to describe stone axes made of rock matching the Stonehenge spotted diabase which H. H. Thomas first described (1923) as coming from the Prescelly Mountains in Pembrokeshire. H. H. Thomas did not himself, I think, use the term.
>
> A. Keiller (who was a personal friend of H. H. Thomas) in a Note on 'Two Axes of Presely Stone from Ireland' (*Antiquity*, vol. X, 1936, p. 220–1) enumerates . . . "examples of implements of 'Preselite' in England and Wales". On p. 460 of this same volume is an Editorial Note referring to a protest by an anonymous correspondent on the spelling used by Keiller for Presely and Preselite, and on Preselite as an "abomination in rock nomenclature".
>
> The Editor and Keiller both defended the spelling after consulting Welsh scholars, and Professor Ifor Williams (pp. 460–2) contributed a long note also defending it and deprecating 'Prescelly'. I have not found the term Preselite in print earlier than 1936 (i.e. the year after H. H. Thomas's death), but it has appeared subsequently in archaeological literature, (e.g. 1962, 1963)."

Selected Bibliography. Brothwell and Higgs (eds.) 1963, p. 485; Evens and others 1962, p. 219; Keiller and others 1941, p. 64; Stone and Wallis 1951, p. 128; Thomas 1923b, p. 239; Wallis 1955, p. 150.

Group XIV

The rock is a camptonite from the Nuneaton district. It has been described by Shotton (1959) as containing deep brown pleochroic hornblende altered to pale green chlorite; colourless to pale purple augite also replaced by chlorite; and crystals of albite-oligoclase. Apatite, biotite, and iron ore also occur.

A thin-section of a stone axe of this group was kindly lent by Professor Shotton who has matched it with material from Griff Quarry. Specimens (E 9718, E 19417) in the Institute collection from this locality, are very similar.

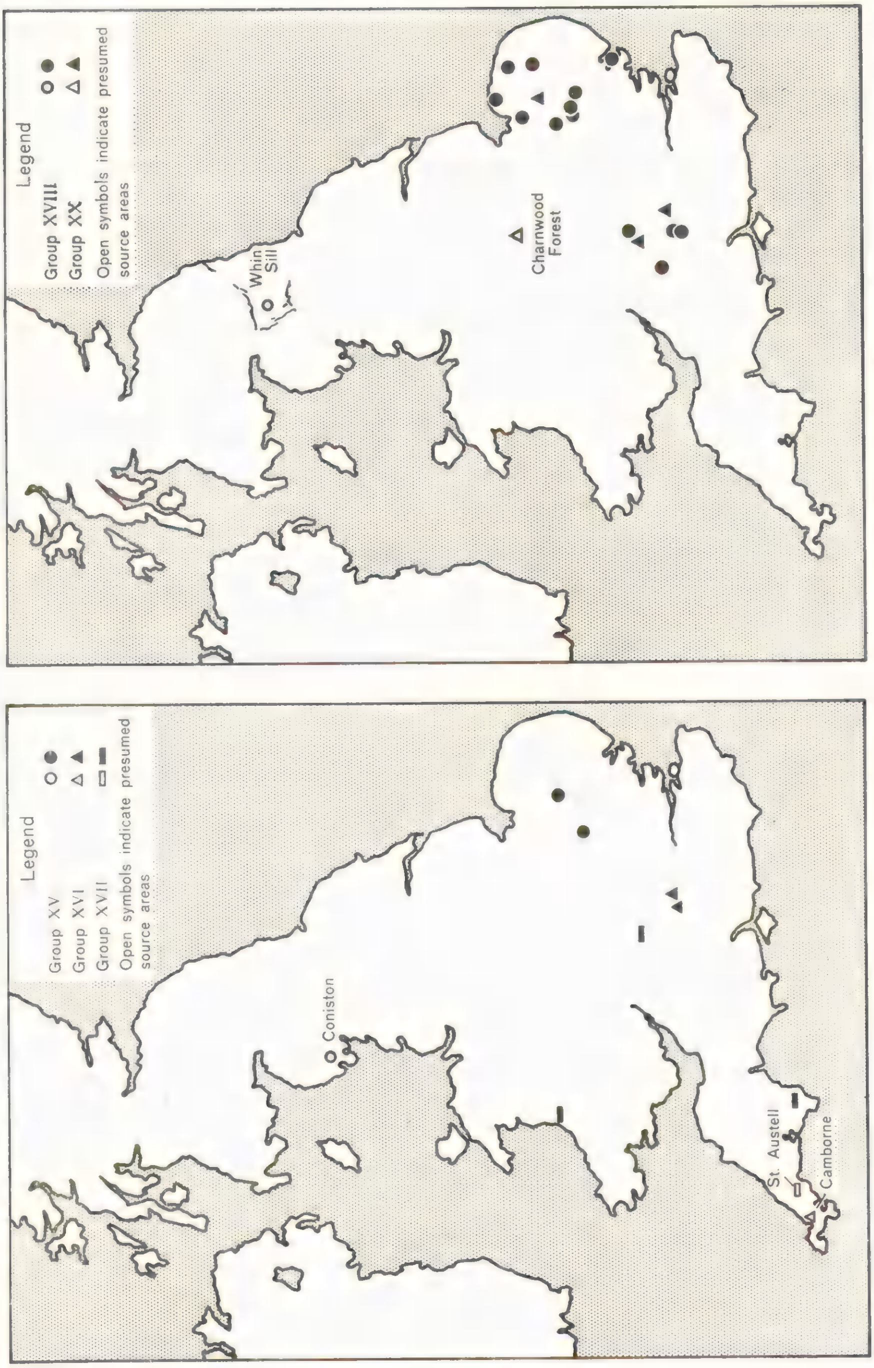

FIG. 5. *Distribution of Stone Axes from Groups XV to XVIII and XX*

There are no examples of stone axes of this group in the collection.

Selected Bibliography. Evens and others 1962, p. 220; Shotton 1959, p. 135; Thomas 1923a, p. 39; Wallis 1955, p. 150.

Group XV (Fig. 5)

A stone axe (ENQ 2026) typical of this group is made of a micaceous sub-greywacke. The rock has been described by Shotton (1959) and he suggests the Coniston Grit of the southern Lake District as its source. The rock contains angular grains of quartz, plagioclase, fragments of felsite and schist, and flakes of muscovite and biotite. The cement contains flakes of chlorite, calcite and iron ore. A few grains of zircon, sphene, epidote and garnet also occur.

There are two examples in the collection: ENQ 1738, Bottisham, Cambridgeshire; ENQ 2026, Feltwell, Norfolk. These match well with specimens of Coniston Grit (E 30139, E 31419) from Windermere, Westmorland.

Selected Bibliography. Evens and others 1962, p. 220; Shotton 1959, p. 137.

Group XVI (Fig. 5)

The rock is an amphibolite (ENQ 1987) containing sheaves and plates of fibrous brownish green hornblende and ragged crystals of iron ore. The feldspar has been recrystallized. A few flakes of biotite, small patches of chlorite and tiny grains of sphene also occur.

The rock has been compared by Wallis (*in* Evens and others 1962) with a greenstone from Camborne, Cornwall. Specimens (E 3924, 3927, 9342) in the Institute collection from this locality are similar. Examples in the collection are: ENQ 1318, Waltham St. Lawrence, Berkshire; ENQ 1726, River Thames, Reading, Berkshire.

Selected Bibliography. Evens and others 1962, p. 220; Wallis 1955, p. 150.

Group XVII (Fig. 5)

The rock consists of a sheared diabase (ENQ 1988) which contains strings of fibrous green amphibole and crystals of iron ore in a feldspar mosaic. A few flakes of biotite and small crystals of apatite also occur. Cornwall has been suggested by Wallis (*in* Evens and others 1962) as the locality for this rock. He states that rock of this type occurs near Kenidjack Castle and at Terras Mill, near St. Austell. Specimens in the Institute collection from Ledenhill Wood (E 3686), Terras (E 6900) and St. Ingungar (E 5488) are very similar.

Examples in the collection are: ENQ 1718, Kendrick's Cave, Aberystwyth, Cardiganshire; ENQ 1624, between Christchurch Meadows and St. Aldates, Oxford; ENQ 1988, Hazard Hill, Devon.

Selected Bibliography. Evens and others 1962, p. 223; Wallis 1955, p. 150.

Group XVIII (Fig. 5)

Stone axes of this group are made from a medium-grained quartz-dolerite (ENQ 1989). The rock contains fresh laths of andesine-labradorite, pale purplish brown augite in crystals and granular aggregates, crystals of a rhombic pyroxene and irregular crystals of iron ore. The pyroxene is altered round the edges to bastite and fibrous amphibole. In addition there are crystals of quartz, a little interstitial micropegmatite, a few flakes of biotite, needles of apatite, and a little chlorite.

The rock is similar to specimens of quartz-dolerite (E 14480, 19053, 25880) from the Whin Sill.

Examples in the Institute collection are: ENQ 912, Swindon, Wiltshire; ENQ 1265, Isleham, Cambridgeshire; ENQ 1589, Peasemore, Berkshire; ENQ 1597, Ashampstead, Berkshire; ENQ 1623, River Isis, Oxford; ENQ 1631, Icklingham Sands, Suffolk; ENQ 1743, Stretham, Cambridgeshire; ENQ 1859, Dovercourt, Essex; ENQ 1871, Tottenhill, Norfolk; ENQ 1872–3, Docking, Norfolk; ENQ 1876, Icklingham, Suffolk; ENQ 2002, Wicken Fen, Cambridgeshire; ENQ 2025, Wymondham, Norfolk; ENQ 2028, Blickling, Norfolk.

Selected Bibliography. Evens and others 1962, p. 224.

Group XIX

The rock of this group is a greywacke (ENQ 1990) containing subangular quartz grains showing a parallel arrangement. Also present are grains of quartzite, mica, feldspar, epidote, chlorite, and sphene. These are set in a cement of siliceous material and sericite.

A Cornish source has been implied by Wallis (*in* Evens and others 1962).

The rock is similar to a specimen (E 6631) in the Institute collection from Nantellan, Cornwall.

There are no thin sections of stone axes belonging to this group in the collection.

Selected Bibliography. Evens and others 1962, p. 226; Shotton 1959, p. 140.

Group XX (Fig. 5)

The rock is described by Shotton (1959) as "a tuff with most particles under 1 mm, but a few up to about 3 mm, many obviously broken and angular, but others sub-rounded. These are chiefly of andesine feldspar, somewhat turbid, much less abundant quartz often with marked strain polarization, and many rock fragments which are mainly andesite but which include a few of quartz porphyry and fine (?) rhyolite. Secondary epidote is abundantly developed as granules in the feldspathic material."

Professor Shotton suggests Charnwood Forest as the source of this rock. Specimens (E 1838, 1880, 1882, 1895) from the Windmill and Hangingstone Hill, both near Woodhouse, Leicestershire, are similar.

Examples in the Institute collection are: ENQ 1217, Cranwick, Norfolk; ENQ 1607, Henley, Berkshire; ENQ 1625, Standlake, Oxfordshire; ENQ 1746, Conington, Huntingdonshire; ENQ 1879, Lound, Suffolk; ENQ 2035, No locality.

Selected Bibliography. Shotton, 1959, p. 141.

Group XXI

Specimens of baked shale (ENQ 1906, ENQ 1908, ENQ 1909) are from the factory site discovered by Houlder (1960) at Mynydd Rhiw, Caernarvonshire. The rock contains fragments of quartz, feldspar, and iron ore in a very fine-grained microcrystalline matrix. Tiny grains of chlorite, sphene, epidote and zircon, and flakes of sericite also occur in the matrix.

A tuff (ENQ 1907) also occurs at the factory site. Tiny welded shards can be seen in the matrix of this fine-grained rock.

There are no thin sections of stone axes belonging to this group in the Institute collection.

Selected Bibliography. Houlder 1960, p. 1; 1961, pp. 108–43.

Additions

Thin sections of stone axes not included in any of the preceding groups are as follows:

(a) An implement of riebeckite-felsite (ENQ 2096) contains phenocrysts of quartz, orthoclase and oligoclase in a fine-grained granophyric matrix. This matrix is crowded with small needles of blue riebeckite. Granules of sphene and epidote also occur.

The implement was given to Dr. Sabine at South Voxter, Delting, Shetland, and the rock is similar to specimens (S 37813, S 28519, S 37803) from North Roe, Shetland.

Dr. Phemister states (1950) that many implements have been discovered in the Shetland Islands made from the rock of the riebeckite-bearing dykes of North Roe. Many of these axes are present in the Lerwick Museum.

Selected Bibliography. Phemister 1950, p. 359.

(b) A medium-grained pyroxene-granophyre (E 19203) from Penmaenmawr Quarry, Caernarvonshire, contains crystals of brown augite partly altered to chlorite and epidote. In addition there are bastite pseudomorphs after enstatite, irregular quartz crystals, some micropegmatite, and laths of oligoclase showing a little alteration to sericite and epidote. Crystals of iron ore and needles of apatite also occur.

A thin section of a stone axe (ENQ 1599) from the River Thames at Clapper Island, Reading, matches this rock (Reading Museum BER 21).

(c) An andesite (E 31418) from Dinas, Caernarvonshire, contains laths of oligoclase-andesine which have been altered to saussurite. Aggregates of small crystals of pale brown augite and bastite pseudomorph after enstatite also occur. These are set in a fine-grained matrix of tiny laths of oligoclase and granules of iron ore, epidote, chlorite and sphene.

A stone axe from Cassington, Oxfordshire (ENQ 1172) (Ashmolean Museum) has probably been made from this rock.

(d) A stone axe (ENQ 1253) from Clegyr Boia, St. Davids, Pembrokeshire, (Williams 1953), now in the Tenby Museum, is made from a crystal tuff containing small grains of quartz and feldspar in a microcrystalline matrix. Tiny flakes of sericite and chlorite occur in the matrix. Grains of iron ore are fairly abundant. The rock can be matched with a specimen in the Institute collection (E 8907) from Porth Hayag, Ramsey Island. It is coarser grained than the rock typical of Group VIII and it also contains more iron ore.

(e) An anthophyllite-cordierite hornfels (ENQ 1729) contains anthophyllite with radiate-fibrous habit set in a mosaic of cordierite and plagioclase. Strings of magnetite are fairly abundant. A few flakes of biotite and prisms of apatite also occur.

The stone axe was found at Bottisham, Cambridgeshire (Ashmolean Museum CAM 8). It is very similar to a specimen in the collection (E 14585) from Kenidjack, Cornwall.

(f) A medium-grained epidiorite (ENQ 1717) contains laths of orthoclase and oligoclase altered to sericite. Plates and fibres of hornblende are pleochroic in bluish green and yellow. Iron ore is abundant as irregular crystals scattered throughout the rock.

The locality of the stone axe is unknown. The rock is similar to specimens (E 7442, E 23767) from St. Keverne, Cornwall. The rock differs from Groups I–III as it lacks augite and biotite and the feldspar is not altered. It contains more feldspar than the epidiorite of Group XVI.

(g) A medium-grained diorite (ENQ 1757) contains crystals of green pleochroic hornblende set in large irregular crystals of feldspar. Apart from a little fresh albite and some prisms of twinned oligoclase, the feldspar has been considerably altered to sericite. There is a little interstitial quartz. Accessory minerals include small crystals of sphene and iron ore.

The axe was found at Capel, Suffolk (Ipswich Museum S 25). It is similar to a diorite (E 13491) from near Cadgwith, Lizard, Cornwall.

(h) A medium-grained olivine-basalt (ENQ 1860) contains phenocrysts of olivine, small crystals of pink augite, grains of iron ore and laths of albite. These are set in a very fine-grained glassy matrix which is variolitic in patches. Long needles of apatite also occur.

The axe, which was found at Dovercourt, Essex (Colchester Museum E 15) was probably made from a glacial erratic. The rock is similar to a basalt (S 12031) of the Dalmeny type from Edinburgh.

Addendum

Since this paper was prepared, an important work by Shotton (1968) has reviewed prehistoric man's use of stone in Britain, and recently Ellis (1969) has studied the petrography and provenance of Anglo-Saxon and medieval English honestones, many of the thin sections of which are in the Petrographical Collections of the Institute of Geological Sciences.

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